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MINETA TRANSPORTATION INSTITUTE

Pavement Condition Survey using Drone Technology

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California State University Transportation Consortium

CALIFORNIA STATE UNIVERSITY Chico

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Timely repairs of pavement defects are essential in protecting both public road and highway systems. Identification of pavement distresses is necessary for planning pavement repairs. This has previously been performed by engineers surveying the roadways visually in the field. As drone usage has progressed, it has become clear that drones are a valuable tool to enhance visual documentation, improve project communication, and provide various data for processing. The use of drone technology has improved both the speed and accuracy of capturing data. Available software has allowed the data to be processed and analyzed in an office environment. This report summarizes the use of drone technology for pavement evaluation for three case studies. Results from this study can be used to deepen understanding of drone use in the process of data gathering for timely repairs for transportation infrastructure.</td></tr>
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Executive Summary

Drones are currently being utilized in many areas of our lives, and many agencies are using drones for construction purposes, stockpile volumes, structures, real estate, storm damage, public safety, and others. For the CP² Center, drone usage has been developed to improve the accuracy, speed, and safety of reviewing and evaluating pavement maintenance treatments. The reviews are done repeatedly over time to determine the expected life of the different innovative treatments and to ultimately develop performance models. These performance models can be incorporated into the MTC StreetSaver, Micro Paver, or other pavement management systems (PMSs).

The Center has three case studies where the reviews have been performed manually and by drone. The manual surveys required traffic control for staff to work on the highway to delineate pavement evaluation sections (PESs) with ground control points (GCPs). Staff then map the pavement distresses by hand using a measuring wheel and drawing the measurements on gridded graph paper while in the field. This method requires two staff members to work in a lane closed to traffic, under traffic control. The drone survey still requires the PESs be delineated for the flight and the placement of some ground control points. The drone flight is done in less than 10 minutes, while the manual mapping of a PES may take as long as an hour or more. After the data is captured in the field, a photogrammetry program is used to process and stitch the photos together. As for the analysis of the pavement distresses, this phase is completed in an office environment by reviewing and annotating the stitched photos and summarizing the data. The Center used PIX4D[1] software for this task, which allowed the data to be summarized and exported to spreadsheets.

Usage of a drone for capturing data, and photogrammetry software for processing the data, allow images to be accurately measured and analyzed. The details captured in a series of photos can be converted into an accurate 2D or 3D output and tied to GPS coordinates. The flights can be programed, using the same flight path, for survey repeatability.

This report validates the three case studies that the CP2 Center used drone technology to capture data for processing and analyzing pavement distresses. The results of our drone surveys will be shared in this report. It is our goal, through this report, to make it easier for others to utilize the benefits of drone technology.

1. Introduction

1.1 Background

A drone can be used as a data collection device which takes high-resolution digital photographs. These photographs capture digital information which can be processed for analysis of many different types of projects. Drone usage is becoming more available for many project types. As drone technology becomes more advanced, different software is becoming more sophisticated and is able to handle various project needs.

Previously, the data collection, processing, and analysis for several innovative projects were performed manually. The crack lengths or other distresses in the travelled lane were measured along a road using a measuring wheel. Then, results were recorded on grid distress mapping survey sheets. The review was performed using two teams of two reviewers. One reviewer recorded observations on mapping forms while the second reviewer took pictures along with recording measuring distance and/or length.

Some of the advantages and benefits of using drone technology include:

- Speeds up the field data collection
- Improves the survey's accuracy
- Lessens the time that the surveyors are in the field
- Better repeatability of the survey
- Specific items in the photographs can be located by GPS coordinates
- Improves safety
  - Lessens the time that the surveyors are exposed to traffic
  - May allow survey to be conducted without traffic control
- Processing the distress mapping can be performed in an office environment
- Summarization of distresses can be performed more easily with software

As technology advances, there are many advantages and benefits of using drone technology in surveying pavement conditions. In many cases, the costs of performing the data capture, processing, and analysis through photogrammetry may substantially decrease surveying costs.

Photogrammetry allows images to be accurately measured with modern camera equipment. The details captured in a series of photos can be converted into an accurate 2D or 3D output. There are five key industries that use photogrammetry with various applications. These include:

- Surveys for mapping
    - Capture data
    - Process
    - Analyze
- Construction projects
    - Inspection of high-rise structures, bridges, or overhead utilities
    - Stockpiles (quantities)
    - Quarry mapping
    - Progress of work
- Agricultural fields
    - Irrigation, such as drainage and uniformity of coverage
    - Plant health
    - Flood damage
    - Spot spraying for pests
- Public safety and emergency response
    - Locate problem
        - View accidents and victims for rescue purposes
        - Disaster assessment (fires, floods, etc.)
        - Facilitate evacuations

- Telecom and inspection
    - Tower inspections (saves having a person climb the tower)
        - Can cut inspection time by 60 percent
    - Vegetation assessment

Caltrans is using drones to improve public safety by monitoring slide areas, traffic accident scenes, and even a geyser in a median area. It is expected that their drone usage will increase dramatically in the near future. The Division of Aeronautics, under Caltrans, has a UAS (spell out) program. There are also drone operating rules that are being developed for Caltrans right-of-ways. The Caltrans Innovation Expo 2022 showed how Caltrans is using drones to enhance their programs.

There are many bridges that Caltrans is responsible for, and each bridge has an inspection schedule to confirm its structural integrity. Drones could dramatically increase the number bridge inspections that Caltrans could perform in a year. The inspection schedule is a minimum of once every two years.

Caltrans or their contractors could use drones to verify construction progress on various highway projects including paving projects. This could save a trip to the field to verify progress payment estimates.

There are new companies continuously developing software for drone technology. Currently, two of the top companies in the field are DroneDeploy and PIX4D.

- **DroneDeploy**[2] advertises as having one of the leading software platforms for commercial drones. This company claims to transform how businesses collect, manage, and interpret drone data. Their software can provide scalable image processing, data storage, and real-time sharable drone maps and 3D models. They have approximately 18 applications listed for various drone usage purposes. https://www.dronedeploy.com/

- **PIX4D**[3] advertises as having the only drone mapping and photogrammetry software tools with a light application, desktop, and cloud platforms. They list three applications specialized for data capture and five apps for meeting various inspection and mapping needs. Their applications support the CraneCamera, viDocRTK rover, and the Parrot Sequoia hardware. https://www.PIX4d.com

- **Skydio**[4] is a new company and advertises having drone autonomy with advanced artificial intelligence (AI)-pilot assistance for complex situations. Their AI Drones are the result of a decade of R&D in computer vision and robotics and offers the user 3D photogrammetry, obstacle avoidance, and complex tracking. https://www.skydio.com/skydio-autonomy?utm_source=bing&utm_medium=cpc&utm_campaign=b_s_brand_ent-v2_brand&utm_term=skydio%20ai&_bt=84662791513713&_bm=p&msclkid=0e3f2d67f53a17da85fc4ed77821d710

- **Litchi**[5] is a software company that offers compatible flight apps for several DJI drone models and has a powerful waypoint mission engine. In Focus mode, it assists the pilot in taking control of both the gimbal and the drone's y-axis, giving the pilot time to concentrate on the horizontal movements. https://flylitchi.com/

One of the top manufacturers of drone equipment which includes an operation platform is DJI. The Phantom 4, one of DJI's older models, has been an industry workhorse for capturing data. This is the drone model that the CP[2] Center used for the three case studies described in this report. Litchi was used part of the time with the Phantom 4 DJI drone to create a layout of an autonomous flight plan for our projects. Litchi is one of the most popular third-party flight apps for DJI drones and has added support for several different drone models.

A remote sensing technology for drones, LiDAR[6, 7] (light/laser imaging detection and ranging), captures more exact data for 3D imagery for measurements as accurate as 2 centimeters. LiDAR creates a point cloud by utilizes laser lights with data ping from the objects on the ground. It should be noted that these points are the raw material for a 3D model. These 3D images don't have the photographic detail and won't give you the colors of items on the ground. To gain color, another sensor or camera is required. It is a highly sophisticated technology that provides an accurate 3D model of the environment; LiDAR calculates hundreds of thousands of points every second. This means that LiDAR requires a significant amount of computing power compared to a camera. It also makes LiDAR prone to system malfunctions and software glitches. Photogrammetry and LiDAR are actually quite different from each other, even if their three-dimensional (3D) outputs look similar. Photogrammetry can provide exceptional results for most missions at a fraction of the cost and complexity of LiDAR. https://wingtra.com/drone-photogrammetry-vs-lidar/?utm_medium=ppc&utm_source=bing&utm_term=drones%20with%20lidar&utm_campaign=Search+-+Bing+-+English+-+US%2C+UK%2C+Canada%2C+Australia+-+001+-+2022+-+Q4&hsa_src=o&hsa_kw=drones%20with%20lidar&hsa_mt=p&hsa_acc=4317485621&hsa_grp=1164383983433385&hsa_ad=&hsa_cam=19152653262&hsa_tgt=kwd-72774696546192:loc-190&hsa_net=adwords&hsa_ver=3&msclkid=c5c5ed56d62f1e4b7e838ef3d1fabc89[6] and https://enterprise-insights.dji.com/blog/lidar-equipped-uavs[7]

Regulations are continuously changing as drone technology and usage expands. There are many agencies that are currently developing rules and regulations for drone flights. Pilots and agencies should be aware of the restrictions for various air space and must coordinate flights with government entities to meet their requirements. The pilot needs to be aware of these requirements prior to making any flights.

1.2 Objective of this report

This report is to validate three case studies that the CP² Center used drone technology to capture data for processing and analyzing pavement distresses. The results of our drone surveys will be shared in this report including the following:

- Equipment
- Software
- Comparison of manual survey results with drone survey results

By sharing how the CP² Center was able to use drone technology for pavement distress identification, it is our goal, through this report, to make it easier for others to utilize the benefits of drone technology.

1.3 Organization of this report

The organization of this report can also be viewed in the Table of Contents.

- Description of manual surveys performed by the CP2 Center
- Description of drone surveys performed by the CP2 Center
- Three case studies using drone survey technology
  - SR 139 near Newell
  - SR 299 at Canby
  - SR 36 near Paynes Creek
- Summary

2. Drone Survey Technology used by the CP^2 Center

Drones may improve distress survey accuracy and allow the development of optimum treatment plans and thus, optimize local agency funds for pavement maintenance. Drones can provide data for pavement repairs, which are an important part of an overall pavement maintenance program. Most local agencies have deferred road maintenance over many years, and there are thousands of miles of public roads that are currently in poor condition. With the new SB-1 funding available for maintenance and construction projects, the importance of selecting proper road maintenance strategies is paramount.

However, as part of any preservation program, there is a need to perform early distress identification to develop a maintenance database. If pavement distresses are not identified and treated, general deterioration will continue. With the aerial photography supplied by a drone, many distresses can be identified and added to pavement maintenance system (PMS). A drone can make it much faster and easier to monitor the performance of pavements and of existing preservation treatments. This report describes using a drone for establishing a pavement distress database on our three case studies. With expanded drone surveys over longer areas of highways, an agency could incorporate this data into their PMS for developing a pavement treatment plan.

2.1 CP2 Center's Transition to Drone Technology

The CP^2 Center had resources available to integrate drone technology into their pavement condition surveys. They had an experienced and qualified pilot available, who also had DJI drone equipment suitable for capturing the pavement distresses. It took time and effort for the pilot to refine the necessary parameters for the various flight plans. Some key items for flight plan development include the following:

- Coordination of planned flight with agencies
    - Select a flight date
- Layout of flight path
    - Consideration of obstacles and other hazards, such as power lines, poles, fences, and trees
    - Traffic control
    - Traffic signs for identifying drone flight limits

    - Place ground control points (GCPs) at specified interval within pavement evaluation sections (PESs)
- Selecting the proper speed for the drone to fly
    - Compute time to complete flight and battery power of drone
- Programing the needed overlap of 60 to 80% for photos
    - Improve photo resolution
        - Allows for classifying distresses, and analysis
- Height above road surface
    - Key to determining drone speed and photo time per shot
    - Plan may need to be adjusted in the field to avoid obstacles and hazards
- Weather, such as rain and wind

The type of camera attached to the drone can affect several of the settings for the parameters listed above. The pilot needs to be familiar with the camera's specifications to determine the proper settings. The drone may also have limits to its capabilities for altitude, speed, flight range, and wind. The GPS' degree of accuracy in drones also varies. These equipment limitations need to be factored into a planned flight. Most of the equipment will have some helpful tables in their instructions.

Even with a knowledgeable pilot and good drone equipment, it took time and effort to find software that met the Center's needs for stitching the photos and having the ability to Payne's measure PIX4Dreact e distances on the stitched photos, such as cracks and other distresses. The PIX4D[7] gave the reviewer this ability, plus the ability to label each distress type and measure and summarize the quantity.

3. Surveys Methods Used by the CP^2 Center

Management had to accept the use of a drone for pavement surveys prior to its incorporation into the project. The drone mapping for surveys had to be shown to be superior to manual survey mapping. Prior to each project, PESs were selected. These PESs were usually 500 feet long, and their locations were agreed upon by the agency and the CP^2 Center. There was always an effort to select PESs that had similar distresses.

3.1 Preparation for Surveying PESs

The manual survey for PES mapping required a measuring wheel, paper mapping sheets, and a crew of four for efficient layout and recording the distress data. Manual surveys should always include traffic control. The drone survey required a drone, a qualified pilot, and a measuring wheel to lay the PESs with ground control points (GCPs). After the GCPs are placed, traffic control may not be needed.

3.1.1 Manual Survey Mapping

The manual survey mapping was done on site under the direction and review of a qualified and experienced pavement engineer with assistance from two senior engineer students. Each PES section was identified in the field and marked off in increments of 50 feet. The crack types and lengths or other distresses in the travel lane were measured using a measuring wheel, and the results were recorded on distress mapping survey sheets. The review was performed using two teams of two reviewers working on the highway with traffic control. One reviewer recorded observations on mapping forms while the second reviewer took pictures along with recording measuring distance and/or length. Each PES was surveyed for distresses prior to an innovative pavement maintenance treatment being applied.

Subsequent surveys have been repeated by the CP^2 Center over several years to judge the performance of an innovative maintenance treatment.

3.1.2 Drone Mapping

Prior to performing the drone survey, a flight plan, as shown in Figure 1, must be established by the drone pilot. The flight plan requires checking for weather conditions on the day and time of flight and coordination between the surveyors, drone pilot, and any agencies that are involved. An onsite review should be performed by the drone pilot to determine if there are any obstacles or hazards.

Figure 1. Flight Plan for PES

Signing for motorists identifying a drone operation were placed in addition to the traffic control signs. GCPs were placed at increments of 25–50 feet on each PES. Some comparisons were done with the manual surveys on PESs on SR 36 in Tehama County. Figure 2 shows Caltrans traffic control for the CP² Center's drone survey. The CP² Center's staff is laying out the GCPs for a PES in the background.

Figure 2. Caltrans Traffic Control for PES Drone Survey

Performing the manual survey was also to confirm the drone mapping was equivalent and more accurate than the manual survey mapping. The distresses of the manual survey and the drone surveys were compared. The drone photographs are identified by GPS coordinates and GCPs. There is a major advantage of the drone survey being repeatable. The measurements were done from captured data and processed using stitched photos with PIX4Dreact[7] software. The drone distress survey analysis was done in the office from the captured, onsite aerial photogrammetry. This software allowed the user to measure the crack lengths on the drone mapping; at the same time, the crack types were labeled, recorded, and summarized. Using this technology, the crack measurements were slightly longer, since more of the crack directional deviations were measured. The crack lengths were measured more accurately using the PIX4D software.

3.2 Identifying other Pavement Distresses

Other distresses include severe rutting, raveling, roping, delamination, bleeding, and potholes. Several of these distresses may be attributed to previous maintenance treatments such as chip seals, slurry seals, or thin asphalt overlays. These distresses are also indicative of the overall pavement performance and have been measured and quantified by manual surveys in the past. These distresses may now be captured, processed, and analyzed using drone photogrammetry programs.

3.3 Summary of Distresses

The PIX4Dreact program allows the user to summarize each distress type and export the summarized data to an Excel spreadsheet. This will make it easier for future surveys to be precisely compared and to determine the deterioration rates for different maintenance treatments by re-inspection of the distresses over time.

4. Drone Survey Case Studies by the CP^2 Center

A drone survey has been done on each of the last three field projects that the CP^2 Center has reviewed. They are on State Routes (SRs) as listed below:

- SR 139 near Newell, California, in Modoc and Siskiyou Counties
- SR 299 near and in Canby, California, in Lassen County
- SR 36 near Paynes Creek, California

4.1 SR 139, Post Mile 34.0/50.7, 0.0/5.0 near Newell, California, Case Study 18

4.1.1 Project Overview

This pilot project was constructed to evaluate the performance of asphalt rubber (AR) (Type II) in comparison to asphalt rubber (Type III). For asphalt rubber (Type III), the High Natural Rubber is replaced with a Polymerized Tire Rubber. Both the asphalt rubber (Type II) and the asphalt rubber (Type III) were placed as single chip seals.

- Treatment 1 – A single layer of 3/8-inch asphalt rubber binder (Type II) chip seal with a flush coat
- Treatment 2 – A single layer of 3/8-inch asphalt binder (Type III) with a flush coat

4.1.2 PES Evaluation

This pilot project includes four test sections as shown in **Figure 3**. Within each test section, two PESs were established for the AR (Type II) and the AR (Type III) for performance monitoring. Each PES is 500 feet long, and the existing condition of each PES was evaluated by the CP^2 Center with detailed crack mapping and photographs.

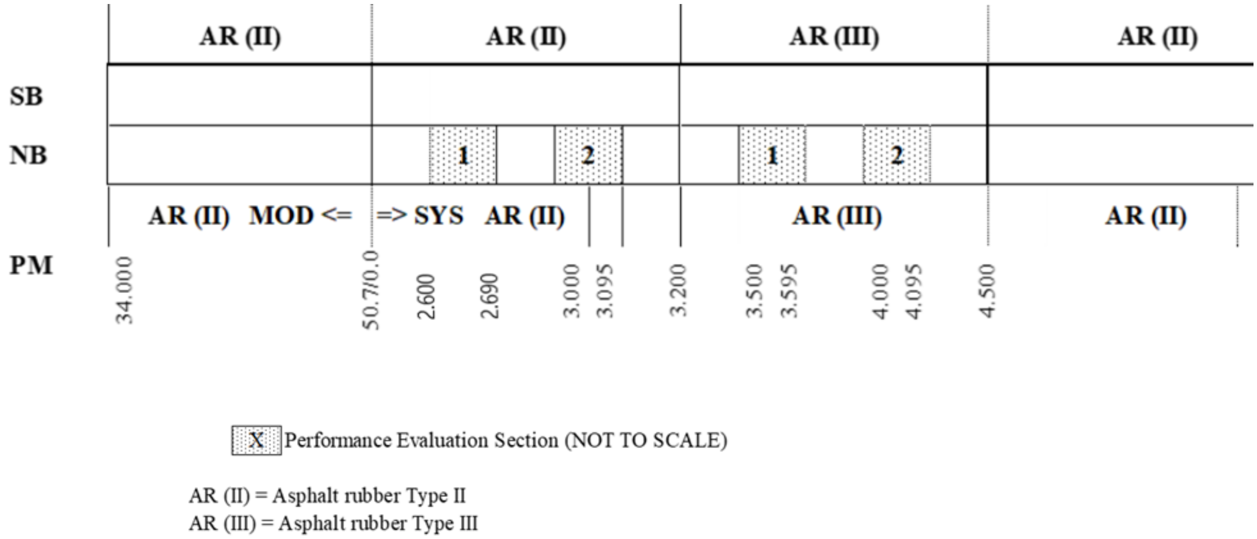

Figure 3. PES Locations for Asphalt Rubber Chip Test Strips on SR 139 (02-1J5204)[8]

4.1.3 PES Drone Survey Comparison with Manual Survey

Besides the cracks being hand surveyed, three of the PESs were flown and photographed by drone. Those pictures are scaled with the PIX4D software, and the results are compared with the hand survey. The drone photographs are identified by GPS coordinates; thus, the original drone flight can be repeated, and new photographs with the same coordinates can be compared with the pre-construction photographs.

Drone summary results for the pavement conditions are available for PES 1 AR (Type II), PES 2 AR (Type II), and PES 1 AR (Type III). The drone flight was incomplete for PES 2 AR (Type III) due to an equipment failure. The analysis between the manual surveys and the drone surveys recapped below do not include fatigue cracking and alligator cracking. With the drone pictures and the manual survey mapping, the fatigue and alligator cracking numbers may be compared later. It should be noted that the manual survey mapping was done on site under the direction and review of a qualified and experienced pavement CE with assistance from two senior CE students. The drone survey was done in-office from the photogrammetry captured and compared to the manual survey. There were differences in the interpretation between the manual survey and the photos captured by the drone. When the drone photos were examined by the same qualified person, there was improved consistency between the evaluations.

SR 139 near Newell, California

For PES 1 AR (Type II), the longitudinal cracking was quite comparable with the manual survey of 912 feet and the drone survey of 852 feet. The difference was caused by some of the miniscule cracks at the centerline not being counted. The manual survey for transverse cracking showed 117 feet, and for the drone survey transverse cracking showed 128 feet. The total of longitudinal and transverse cracking for PES 1 AR (Type II) for the manual survey was 1,028 feet and for the drone survey was 980 feet for a difference of 49 feet or 4.8 percent.

For PES 1 AR (Type III), the longitudinal cracking was 827 feet for the manual survey, and 809 feet for the drone survey. The manual survey for transverse cracking showed 92 feet, and the drone survey showed 64 feet. The total of the manual survey for longitudinal and transverse cracking was 919 feet, and for the drone survey the total was 809 feet. The difference of total cracking was 46 feet or 5.0 percent. Again, some of the difference was caused by the variance in interpretation of the centerline cracking. The difference in the transverse cracking was probably caused by the way the small cracks were evaluated.

For PES 2 AR (Type II) the longitudinal cracking was 954 feet for the manual survey, and 1028 feet for the drone survey. The manual survey for transverse cracking showed 52 feet, and the drone survey showed 55 feet. The total of the manual survey for longitudinal and transverse cracking was 1,053 feet and for the drone survey the total was 1,083 feet. The difference of total cracking was 30 feet or 2.8 percent.

The average difference between the drone survey and the manual survey for longitudinal and transverse cracking was 4.2 percent. Again, fatigue cracking and alligator cracking were not included for this analysis. It is our consensus with further development on "Drone Photogrammetry," the results will equal, if not exceed, current manual survey mapping practices. Centerline cracking is usually caused by the construction joint at the centerline, and perhaps these cracks should be placed in a separate distress category.[8]

4.1.4 Pre-Construction Photos, SR 139 near Newell

PES 1 AR (Type II), PM 2.600 to 2.695

Figure 4 shows the ground photos of the start of PES 1 AR (Type II) with the identification board.

Figure 4. Ground Photos (Lt.) Start PES 1 AR (Type II) Identification Board,
(Rt.) Looking North

Figure 5 shows PES 1 AR (Type II) a right lane photo looking north from PM 2.6 from the overhead drone. Figure 6 in the left photo shows PES 1 AR (Type II) lane drone photo between Station 1+00 and 1+25, and the right ground photo at Station 1+50. The fatigue cracking is much more apparent from the overhead drone photo than the ground photo taken from the right side of the lane.

Figure 5. PES 1 AR (Type II) Right Lane Drone Photo Looking North from PM 2.6[8]

Figure 6. Lt. PES 1 AR (Type II) Lane Drone Photo Between Sta 1+00 and 1+25, Rt. Ground Photo at Sta 1+50

Figure 7 show an example of a PES which is stitched and annotated using PIX4D software. The overhead drone photos show the fine fatigue cracking with very good detail, making annotation and analysis much easier than using the manual surveys. Also, the evaluator is not rushed in identifying the distress type.

Figure 7. Example of Stitching using PIX4Dreact Software

Figure 8 shows similar PES photos stitched using DroneDeploy, another photogrammetry software. PIX4D software supplied better photo stitching results than DroneDeploy software for the pavement crack analysis in **Figure 8**. [8]

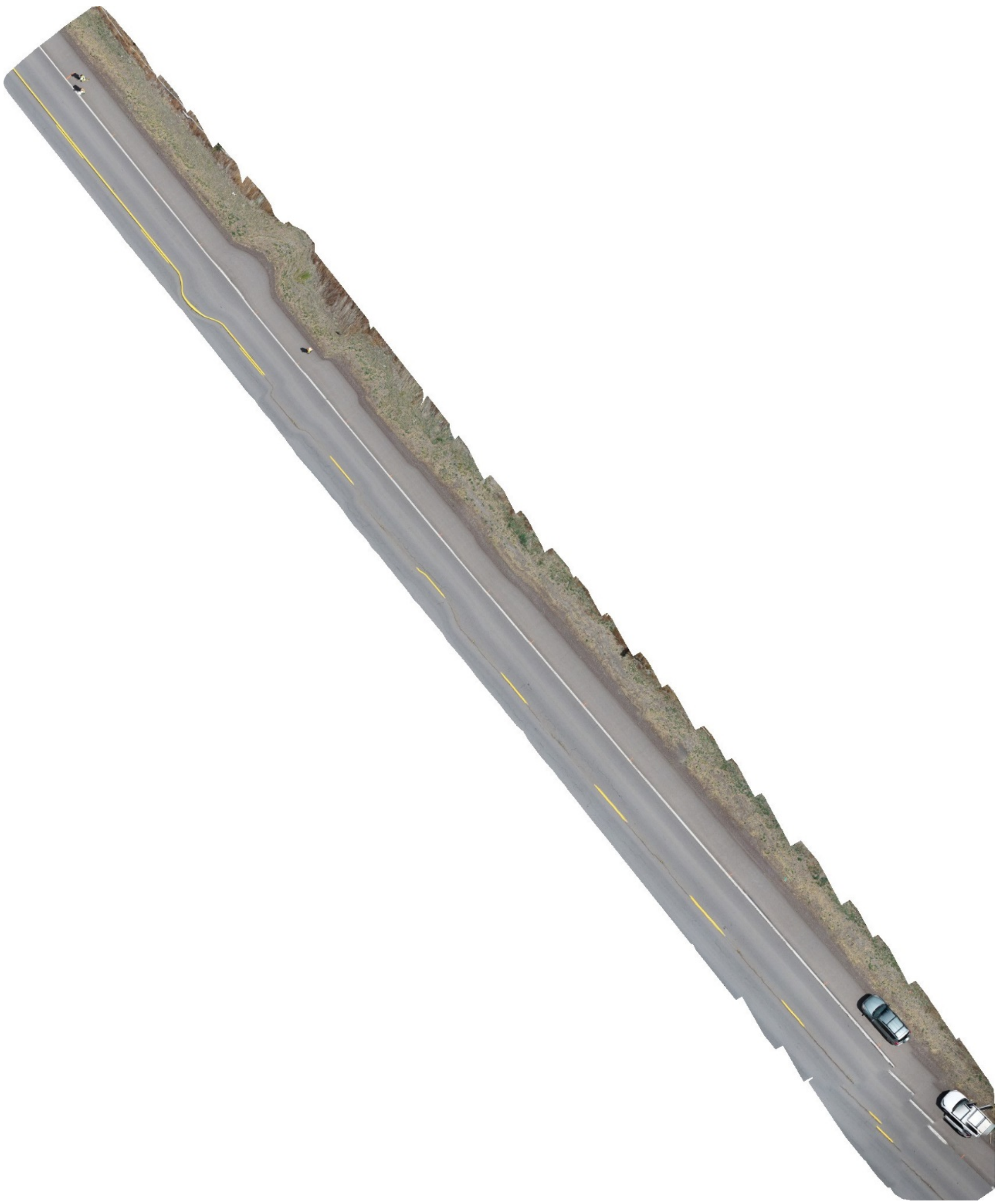

Figure 8. Example of Stitching using DroneDeploy Software

Figure 9 shows an example of the manual survey results for AR(II) PES 1. The manual survey mapping may be prone to more errors when drawn under field conditions.[8]

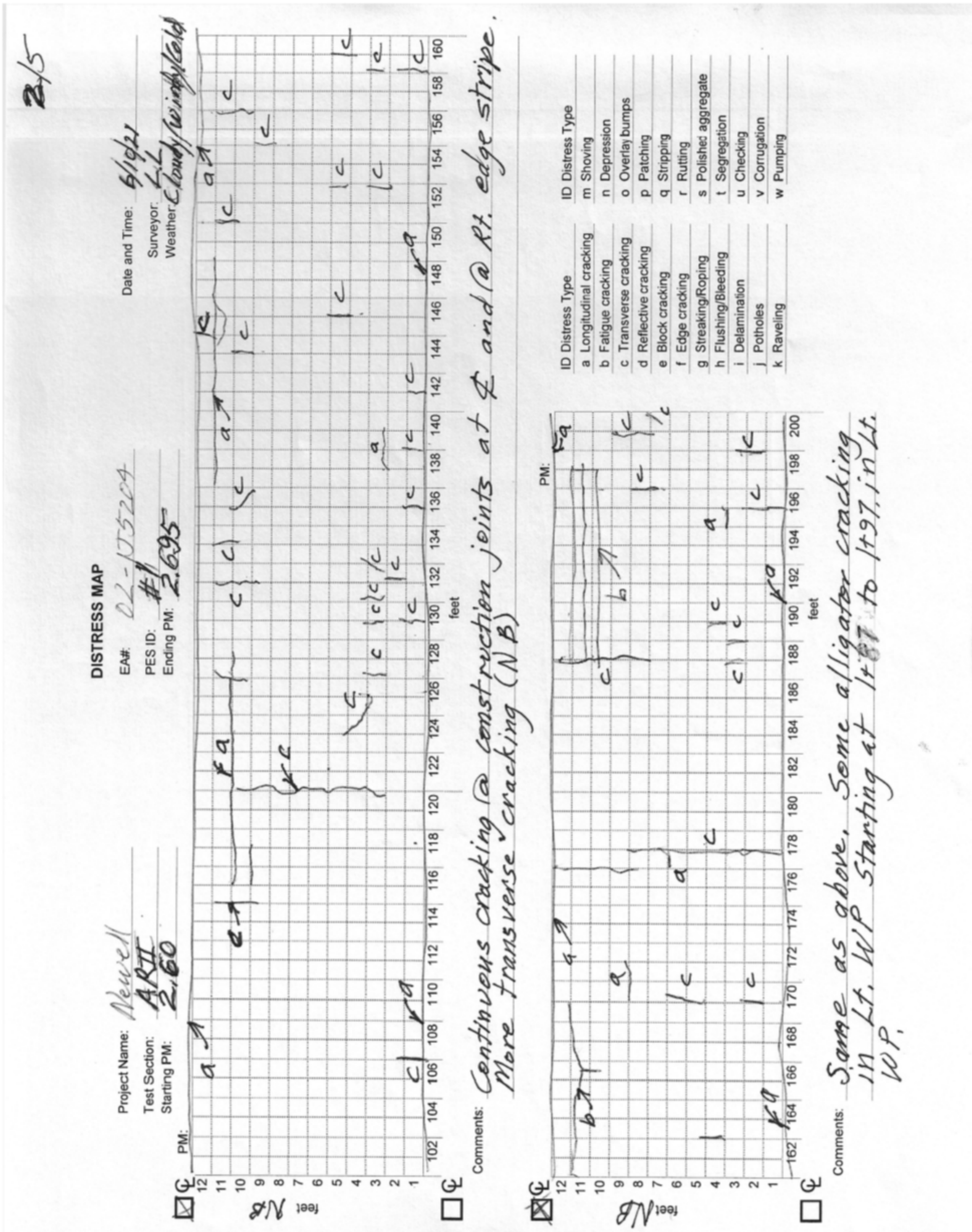

Figure 9. Example of Manual Survey Mapping[8]

4.2 SR 299, PM 20.0/23.1 near Canby, California, Case Study 2

4.2.1 Project Overview

This pilot project was constructed with multiple test sections as shown in Figure 10. Within each test section, two PESs were established to performance monitor each chip seal binder PES. Each PES is 500 feet long, and the pavement condition of each PES prior to chip seals was evaluated by the CP² Center with detailed crack mapping and photographs. The results were used as a baseline for the initial performance evaluation of each test section.

- Treatment 1 – A single layer of 3/8-inch asphalt rubber binder (Type II) chip seal with a flush coat.

- Treatment 2 – A single layer of 3/8-inch asphalt binder (Type III) with a flush coat.

4.2.2 PES Evaluation

The survey results of each PES were used as a baseline for the subsequent performance evaluations.

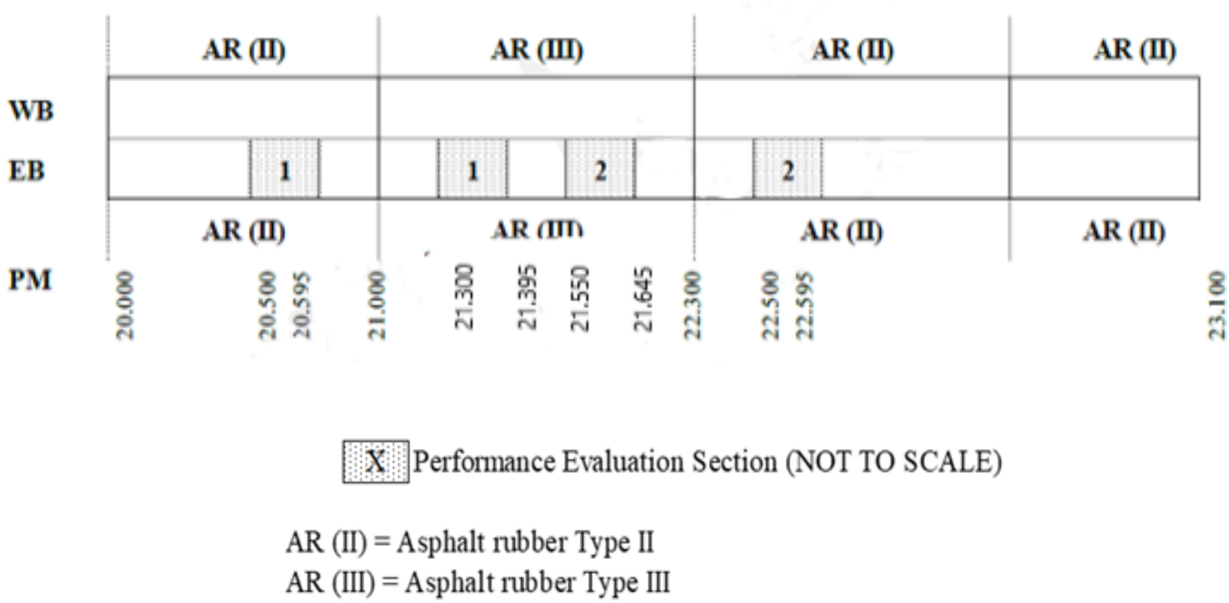

Figure 10. PES Locations for Asphalt Rubber Chip Test Strips on SR 299 (EA 02-1J4404)

Table 1 shows a summary table of the cracking for this project on SR 299 near Canby, CA. The cracking identified in the drone photos is shown in blue. In most cases, the total cracking summarized by the manual survey and the drone survey are close. Some differences may be due to different reviewers making different interpretations.[9]

Table 1. PES Cracking Condition Summary[9] (Linear Feet and Square Feet)

Distress	PES 1 AR (II)	PES 2 AR (II)	PES 1 AR (III)	PES 2 AR (III)	Total
Longitudinal Cracking (LF)	333 354	268	403 376	61	1,065
Patching at Recessed Markers (LF)	16 19.12	0	23 27.57	0	0
Alligator B Cracking Low to Medium Severity (ft.^{2})	0	0	0	0	0
Transverse Cracking (LF)	148 146	37	123 124	177	485
Raveling Square Feet	2,755	2,500	1,884	2,500	9639
Digout Square Feet	0	0	816	0	816
Total (LF) Cracking	481 519.12	305	526 527.54	238	1502

Notes:

1) No fatigue cracking or alligator cracking was identified in these PESs.

2) The cracking identified in the drone survey is shown in blue.

3) Measurements done in linear feet for longitudinal and transverse cracking, and this table summarizes each labeled distress from each PES from the mapping survey.

4) Lane widths were less than 12 ft. and were closer to 11 ft. in most of the PESs.

5) Measurements for raveling are shown by square feet. All of the PESs showed continuous raveling in both the left and right wheel paths.

6) PES 1 AR (Type III) had a digout, 4 feet wide, in the right wheel path (total 816 square feet).

7) Patching at recessed markers on the centerline was modified from the overhead drone photographs for the PES cracking condition summary. The actual drone measurements are more accurate for these values. Minor discrepancies of longitudinal cracking numbers in PES sections appear in the centerline cracking evaluation.

Figure 11 shows an overhead drone photo looking west covering the area of both PES **1** AR (Type II) and PES 1 AR (Type III) prior to construction of the chip seal coats.

Figure 11. Drone Overview (Raw photo) of PES 1 AR (Type II), and PES 1 AR (Type III) Look West Prior to Construction of Chip Seal Coats[9]

Figure 12 is a raw drone photo showing the typical highway distresses for this section of SR 299 near Canby, CA. The rutting and rock loss from chain wear shows, as well as the transverse thermal cracking and longitudinal cracking. Canby is in a high desert environment in northern California.

Figure 12. Raw Drone Photo Showing Typical Highway Distresses[9]

Figure 13 is a stitched photo showing PES 1 AR(II). The distresses are also apparent in the stitched photo. With proper overlap of the raw photos, the stitched photo may appear clearer than the raw photos. Recommended photo overlap may be as much as 80 percent.

In Figure 14, the left photo shows a depicted rutting area of 37.769 ft^2 as annotated with PIX4D software. The right photo shows the latitude and longitudinal location as 41.4258291, -120.8965235, based on the US National Grid Reference: 10T FL 75767 88165. This is typical information captured in a drone survey.

Figure 13. Stitched Photo of PES 1 AR(II)

Figure 14. (Lt.) Rutting Area of 37.769 Ft^2 as Annotated with PIX4D Software, (Rt) Location: 41.4258291, -120.8965235, US National Grid Reference: 10T FL 75767 88165[9]

4.3 SR 36, PM 20.0/23.1 near Paynes Creek, California, Case Study 3

4.3.1 Project Overview

In 2013, Caltrans and industry jointly developed pilot specifications[10] for construction of pilot chip seal projects to evaluate the performance characteristics of chip seals using the AR II and CRR18MB with and without WMA additives. The WMA used was Sasobit GTRM 850 produced by Sasol Wax North America for both the AR II and the CRR18MB. This pilot project took place September 2013, in northern California, with various PESs for each maintenance treatment type. Since their construction, they have been evaluated using manual survey methodology at 1-year, 3-years, 4-years, and 8-years. The last evaluations were done in 2022 using manual survey for several PESs and drone survey technology used for all of the PESs.

The treatment types include the following:

- AR Type (II)
- AR Type (II) with WMA
- CRR18MB
- CRR18MB with WMA

4.3.2 PES Evaluation

This pilot project was constructed with multiple test sections as shown in Figure 15. Within each test section, four PESs were established for performance monitoring of each chip seal binder with and without WMA for a total of 16 PESs. Each PES is 500 feet long and the pavement condition of each PES prior to chip seals was evaluated by the CP^2 Center with detailed crack mapping and photographs. The results were used as a baseline for the initial performance evaluation of each test section.

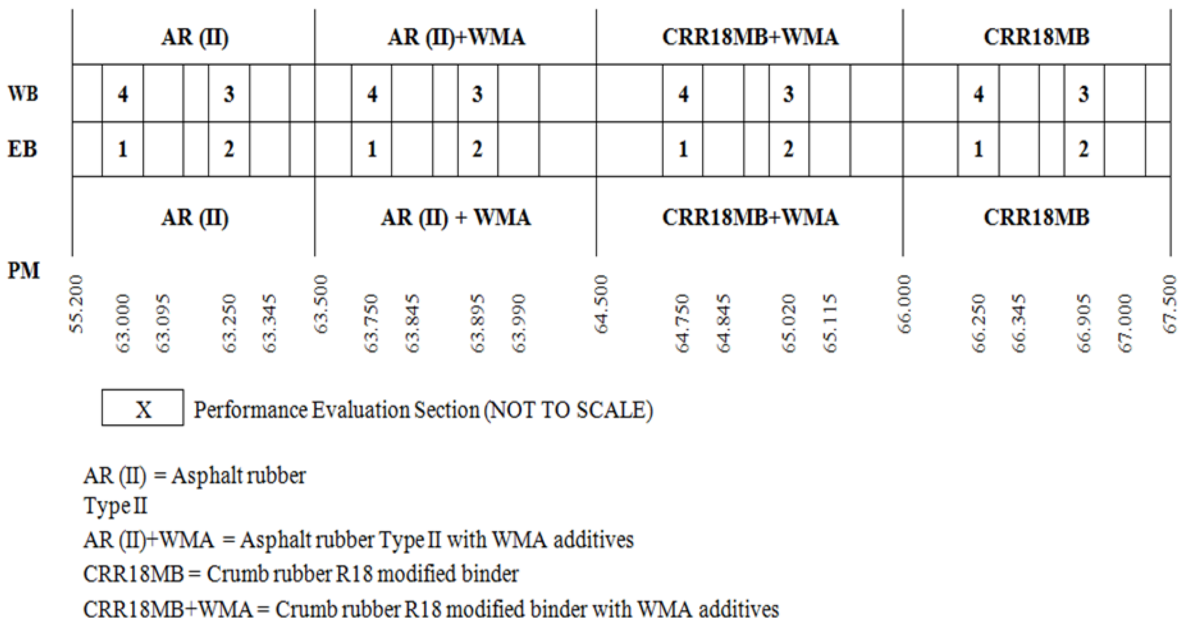

Figure 15. Tehama 36, PES Layout for Four Chip Seal Treatments[11]

Of the 16 individual PESs, only two were analyzed for cracking, using both the manual survey method and the drone survey method. Those PESs were the CRR18MB PES 2 and PES 3, located on the east end of the project. Figures 16, 17, 18, and 19 show typical shots taken from the ground during the course of a manual survey.

Figure 16. Student Assistants Surveying CRR18MB PES 2, and Placing GCP for Stationing

Figure 17. CRR18MB PES 2, Looking West Bound near PM 66.90 at Beginning of PES

Figure 18. CRR18MB PES 2, Typical Cracking between Sta. 4+00 and Sta. 4+50

Figure 19. PES Identification Post

Figures 20 and 21 show more typical photos used to supplement either a manual survey or an overhead drone survey.

Figure 20. CRR18MB PES 3, Typical Longitudinal Cracking between Station 4+90 and Station 5+00

Figure 21. CRR18MB PES 3, Typical Longitudinal Cracking

Figure 22 shows an example of the typical manual map survey of PES 2, CRR18MB. Again, this survey may be more prone to errors during analysis. Various reviewers may perceive a different type of distress.

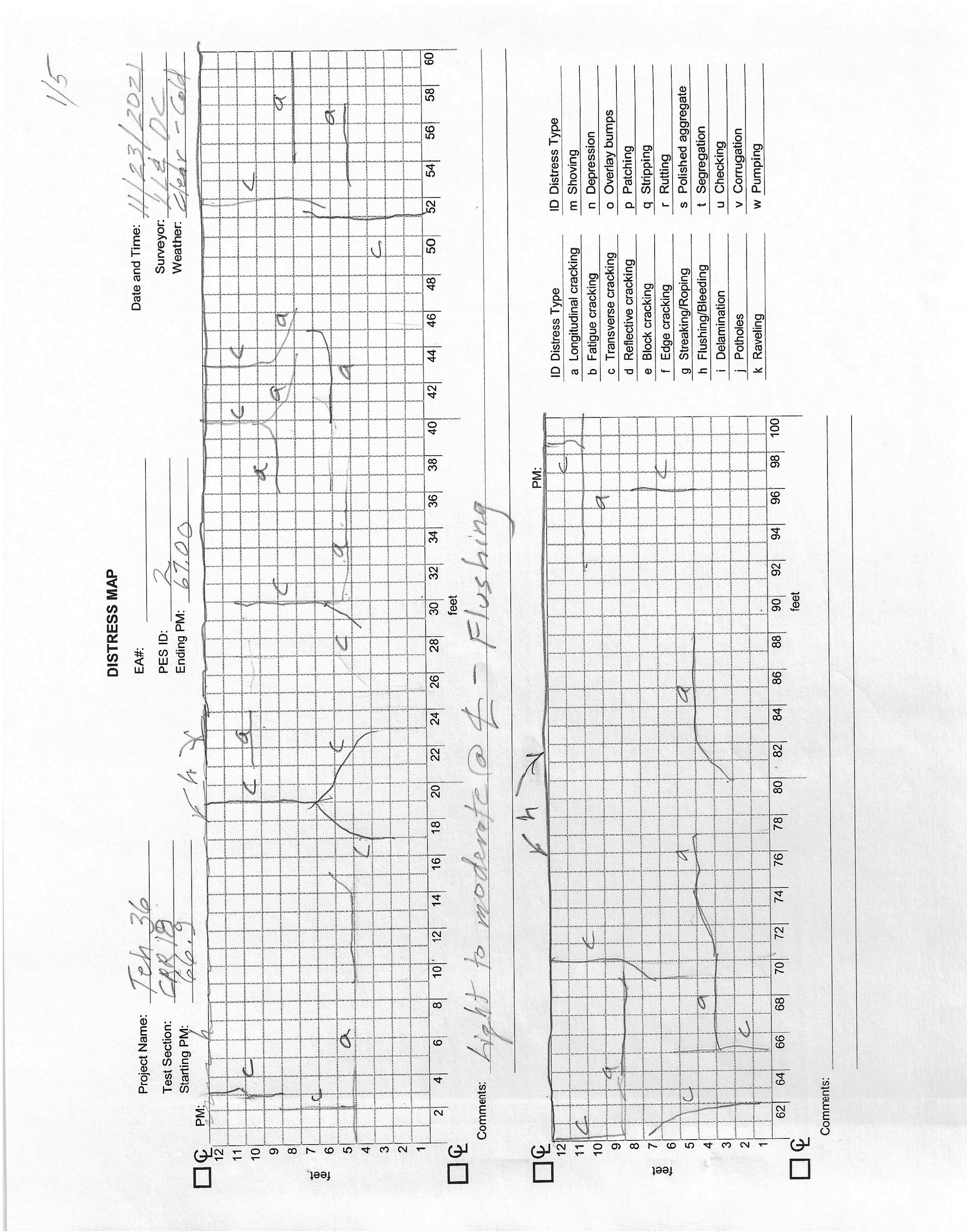

Figure 22. Typical Manual Map Survey of PES[12]

This review allowed the CP2 Center to perform a more detailed analysis of the distresses from the overhead photos that were taken with a drone. The **PIX4Dreact** photogrammetry program stitched the individual drone photos together for a detailed analysis of each PES. Besides having the overall view, the user of this program could "zoom in" and electronically measure each individual crack or distress. This allows the different individual distress types to be summarized in a table within the program which can be exported. It was confirmed that with the drone photos and photogrammetry technology, the data was more refined and accurate. Furthermore, the distress summaries could be made in the office. By reducing the time on the highway, it minimizes traffic control costs and keeps all staff safer. **Figure 23** shows an example of distress analysis performed from a drone photograph on an AR(II) WMA and shows the latitude, longitude, and elevation above sea level. This drone photo was taken from an approximate elevation of 40 feet above ground level (AGL). The technical advantage of the drone photo analysis is that it is repeatable with a high degree of accuracy.

Figure 23. Typical PIX4D Programs used for Data Collection, Process, and Analysis12

4.3.3 Survey Steps Using More Advanced Software from PIX4D Website[13]

"Once the data was collected with PIX4Dcatch, the surveyor transferred the data to PIX4Dmatic, the desktop photogrammetry software. PIX4Dmatic is a powerful product that can handle both large scale projects from corridor flights[13] by drones as well as terrestrial surveying with PIX4Dcatch. As PIX4Dcatch collects both LiDAR and photogrammetry data, it has a variety of imagery and information available for processing. PIX4Dmatic has specially designed features to handle this workflow with PIX4Dcatch, and provides users with the option to create photogrammetry point clouds, LiDAR point clouds, or a combined one with both datasets[14] in it (also known as dense, depth, and fused point clouds). It also has noise and sky filtering options[15] to ensure a tidy point cloud with minimal disruption. This saves time on editing the point cloud after processing." https://www.PIX4d.com/blog/PIX4dmatic-sensefly-large-dataset[13]

"Processing took less than 3 hours, after which the point cloud was exported to PIX4Dsurvey. This software vectorizes point clouds, including automated features such as automatic road marking or identifying of elements like manhole covers. PIX4Dsurvey enables users to move from processing and analysis to design elements as it extracts data for use in CAD, filling the missing gap between photogrammetry and CAD." https://www.PIX4d.com/product/vidoc-rtk-rover[16]

5. Summary

Currently, many industries use drones to improve the precision, safety, and speed of acquiring data. Many software packages are being used in agriculture, roofing, construction, project inspection, quarries, oil and gas, or safety. A drone can capture the data, and software can process it for analysis. The CP² Center has found that the pavement condition survey time in the field can be substantially lessened, thus shortening traffic exposure time and increasing safety. At times, the drone survey can even be performed with live traffic.

After the data is captured, it can be processed with photogrammetric software for mapping purposes. The maps can be analyzed for pavement distress in an office environment. With high resolution photography, that is scalable, the measurements can be made and summarized in the office.

With highway maintenance activities, it is very likely that GCP may be obliterated over time. This makes it very time consuming to reestablish the PES limits for repeat surveys. The distress at one, two, or even eight years later must be quantified in order to judge how different innovative pavement preservation treatments are performing. The drone photographs have GPS coordinates associated with each individual photograph before it is stitched into a panorama. With GPS coordinates, flight paths can be duplicated, the data is more accurate, and the PESs can be more easily relocated.

As the need for precision of the final product increases, the cost of the equipment can increase dramatically. If Lidar is integrated with the photogrammetry, the equipment may cost over $30,000.[17] One advantage of Lidar is that the data point clouds can be created under tree canopies.[18]

6. Recommendations

Before investing in equipment and skilled personnel to operate the equipment, evaluate your long-term needs for photogrammetry or Lidar. If you do not need a drone for photogrammetry on a regular basis, it may be more cost effective to contract out your company's photogrammetry needs. It is a rapidly changing industry regarding software, hardware, as well as various regulations.

If it is necessary to have your crew work in an active construction zone or traffic, a drone can shorten the time that the crew is in an active work zone or live traffic. Keeping workers away from traffic can prevent accidents.

Consider the cost differences between having a drone capture data versus having several crew members in the field performing a manual survey. With a drone, the data processing time also may be lessened. In addition, consider the cost difference of investing in Lidar over using regular photogrammetry technology. Lidar can improve the precision, but RTK can also improve data precision.

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Terminology and Acronyms

Chip Seal: A bituminous binder is applied followed by aggregate application and rolling to embed the aggregate into the binder.

Distresses: Deterioration resulting from factors including the environment, construction, and design practices, material selection, or load on pavement. These distresses include longitudinal cracking, transverse cracking, fatigue cracking, rutting, raveling, flushing, edge cracking, and potholes.

DroneDeploy: A photogrammetry and geospatial software package that allow the user to measure from images. This unique photogrammetry software suite is suitable for mobile and drone mapping. It can automate flight of a drone and capture, measure, and export your data in minutes with built-in analysis tools. This company offers a free trial subscription.

Flush coat: A light application of asphalt emulsion and sand to lessen the loss of chips and helps protect motorists from broken windshields.

Litchi: A drone software package that is compatible with DJI drone hardware. It gives the pilot the ability to set waypoints for a flight pattern and to set specific flight paths.

MTC StreetSaver: Pavement management systems (PMSs) commonly used by government entities.

Micro Paver: Pavement management systems (PMSs) commonly used by government entities.

Pavement Preservation: The practice of utilizing a cost-effective system that allows for the tracking and recording to extend and enhance the quality and life of a pavement. In addition, preservation would serve to improve safety and provide good ride quality. The system primarily focuses on preventive maintenance as a cost-effective way to treat roadways and improve the quality of the road. These treatments may include chip seals, microsurfacing, slurry seals, cape seals, or thin asphalt overlays.

PIX4D: A photogrammetry and geospatial software package that allow the user to measure from images. This unique photogrammetry software suite is suitable for mobile and drone mapping. Other PIX4D packages are PIX4Dsuvey, PIX4Dmatic, and PIX4Dcloud. PIX4DReact is a "junior" version of their mapper that is often used by first responders in rescues.

Preventive Maintenance: Cost-effective strategy to preserve the roadway and prevent deterioration in addition to improving or maintaining the condition of the roadway. This is typically performed early, before significant structural deterioration appears. Some activities include joint sealing, crack sealing and filling, as well as utilizing chip seals and slurry seals.

Routine Maintenance: Maintenance performed routinely to preserve the roadways or to return the roadway to a proper level of service. Some maintenance activities include crack filling and/or sealing, as well as maintaining the drainage system, both of which are performed throughout a pavement's life.

Skydio: A newer US company that offers a drone package which includes 3D photogrammetry, obstacle avoidance, and complex tracking. They offer several different drone models.

Surface Type: Surface type is the uppermost layer of a pavement structural section and is dependent on the type of material used (HMA or Portland cement). The surface type also depends on the functional class (arterial, collector, or residential).

Treatment Type: A certain treatment used to treat specific distresses on a roadway. These treatments would include chip seals, slurry seals, microsurfacing, Cape seals, and thin HMA overlays. For some situations, treatment combinations are required to ensure quality performance of the roadway.

Acronyms

AI	Artificial Intelligence
AR	Asphalt Rubber
Caltrans	California Department of Transportation
CCPIC	City and County Pavement Improvement Center
CP2C	California Pavement Preservation Center
DOT	Department of Transportation
FHWA	Federal Highway Administration
GCP	Ground Control Point
HMA	Hot Mixed Asphalt
MTI	Mineta Transportation Institute
PES	Pavement Evaluation Section
PMS	Pavement Management System
R&D	Research and Development
TRB	Transportation Research Board

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