# EVALUATION OF LIDAR FOR HIGHWAY PLANNING, LOCATION AND DESIGN

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## ABSTRACT

Surface terrain information is required to economically site new or relocate existing infrastructure facilities and make final design plans. Currently, field surveying and photogrammetric mapping are the most widely used methods to acquire these data. However, these methods are time and resource intensive as significant data collection and reduction is required to provide the level of detail necessary for facility location and design. Light Detection and Ranging (LIDAR) is a relatively new alternative technology to obtain terrain information more efficiently. With LIDAR, data can be collected under a variety of environmental conditions, including low sun angle, cloudy skies, and even darkness, resulting in expanded windows for data collection. While less accurate than photogrammetric mapping, LIDAR presents the opportunity to expedite the highway location and design process by providing designers with preliminary terrain information earlier in the process. This paper presents a proposed methodology for utilizing LIDAR in conjunction with photogrammetric mapping to speed up highway location and design activities, including estimates of time and cost savings.

## INTRODUCTION

Accurate surface terrain information is required for locating new or relocating existing transportation facilities. Three methods are currently used by DOTs for large-scale elevation data collection: Electronic Distance Measurement (Total Station), Real Time Kinematic (RTK) (GPS), and photogrammetry. Both EDM and GPS methods are highly accurate. Data from both methods are rapidly processed for use in the office once data are collected in the field. However, data collection in the field is time-consuming since equipment and workers must be moved throughout the study area. As a result, both EDM and GPS are impractical for large-scale location or relocation studies. When large area data collection is necessary (between 30 and 100 acres depending on the project) photogrammetry is more feasible than other data collection methods (Garber and Hoel, 1997). Consequently, the majority of DOTs use softcopy (digital) photogrammetry to collect elevation data to describe ground surfaces for design purposes. In softcopy photogrammetry, digital raster images are utilized (rather than hardcopy aerial photos) to perform photogrammetric work (Kavanagh and Bird, 2000). Instead of producing hard copy aerial photos, imagery taken during a flight is processed through high-resolution scanners to produce digital images. The digital nature of the data allows terrain mapping to be accomplished in an efficient manner through automation. The aerial photography collected also provides a visual record of the study area. The majority of photogrammetry is performed in the office once aerial photography is flow and ground control is laid out in the field.

Although widely used to acquire surface terrain information, photogrammetry does have several limitations that adversely affect the location process. Traditionally, the imagery acquired to obtain photogrammetric data must be taken during leaf off conditions (no leaves on trees) with the ground free of snow. This eliminates any “clutter” which could potentially affect the final results of the work, particularly derived elevations. At the same time, the sun must be at a proper angle (above 30 degrees) with cloud free skies. For most locations in the U.S., this limits the data collection window to about four hours a day (10:00 a.m. to 2:00 p.m.) year round. As a result, collection of aerial photographs is limited to early spring or late fall to accommodate the leaf-off and sun angle limitations which limits data collection opportunities. Waiting for optimal flying conditions may create a backlog of projects for which tasks cannot proceed until the necessary mapping products are available. Additionally the actual process of collecting elevations from the images is time consuming and further slows the process.

Highway agencies often attempt to streamline the process to reduce the time required to plan and design highway projects. Since the acquisition of aerial images is limited to narrow windows during the year and during the day, some agencies choose to collect and process more terrain data and imagery products than they will ultimately need, in order to be able to rapidly respond to changing location decisions without having to perform additional data collection activities. While expediting the planning process, additional data collection and processing is expensive. Therefore, any technology which has the potential to expedite data collection activities would be advantageous. The objective of this paper is to present a methodology for expediting terrain data collection through a combined use of LIDAR and photogrammetric mapping.

## LIDAR

The most considerable disadvantage of current data collection methods is that a significant amount of time is either required in the field to collect (EDM and RTK GPS) or to reduce the data in the office (photogrammetry). LIDAR has shown promise for collecting terrain information more rapidly than the existing data collection techniques. LIDAR is an active remote sensing system that utilizes a laser beam as the sensing carrier (Wehr and Lohr, 1999). Laser scanners measure three-dimensional points on the surface of the earth (Haala and Brenner, 1999). An aerial platform (usually an airplane) has a laser ranging system mounted onboard, along with other equipment including a precision GPS receiver and accurate Inertial Navigation System (INS) to orient the platform (Shrestha, et. al. 1999). The platform is flown over the area in which data are to be collected while scanned by the laser. The lasers utilized in this process typically emit thousands of pulses (up to 25,000) per second while in use. The travel time of these pulses is timed and recorded roundtrip between the platform and the ground along with the position and orientation of the platform to determine range (distance) (Shrestha, et. al. 2000). Elevations are derived from the distance measurements. Digital aerial photography can also typically be collected at the same time as LIDAR data, providing an additional layer of data, assuming conditions such as cloud cover are favorable.

In order to expedite the location process, several DOTs have explored the use of Light Detection and Ranging (LIDAR) to collect surface terrain information. Projects in Texas, North Carolina, Minnesota, and Virginia have all examined how LIDAR can be utilized to expedite location and design activities (Langston and Walker, 2001, Johnston, 2001, Minnesota Department of Transportation, 2002, Virginia Department of Transportation, 2001). While some projects did realize significant time and cost savings ($1.5 million dollars and 9 months in the case of Texas), the conclusion drawn from all of these projects was that LIDAR could not completely take the place of traditional mapping methods (Langston and Walker, 2001). Photogrammetric data is still required to produce highly accurate terrain models, as well as additional data, such as breaklines. However, the use of LIDAR in the early stages of highway location, before highly accurate terrain information is required, may provide tangible time and cost savings.

LIDAR is attractive because data can be collected and reduced fairly rapidly compared to traditional photogrammetry. LIDAR can potentially be collected under a much wider range of conditions than aerial photography, including winter months if snow cover is not present (Veneziano, Hallmark, and Souleyrette 2002).

Additionally, aerial photography can be taken at the same time to provide a visual record without worrying as much about sun angle. LIDAR can also be flown at night or under adverse light conditions to provide an initial surface model to begin preliminary alternative studies and then aerial photography for a visual reference or future photogrammetry flown at a later date under more optimal environmental conditions.

## LIMITATIONS

Being a relatively new technology, LIDAR has its rough spots. Research conducted by Huising and Pereira classified LIDAR errors into broad groups including laser, GPS/INS, and filtering induced, as well as errors caused by other problems (Huising and Pereira, 1998). Laser induced errors stem from changes in height for the points on the terrain surface at a narrow angle (ridges and ditches), and grain noise, which makes a smooth surface (beaches) appear rough (Huising and Pereira, 1998). GPS/INS errors stem from equipment initialization errors and variances in the measurements taken by the instruments (Huising and Pereira, 1998). Filtering errors stem from the incomplete and/or unnecessary removal of features, which may or may not be desired in the final dataset (vegetation, buildings, rock outcroppings). Other causes of error can stem from incomplete coverage of the survey area from improper flying and water bodies reflecting beams instead of absorbing them, producing a false reading (Huising and Pereira, 1998). These errors, either alone or in combination, can result in inaccurate elevations being produced.

Ideally, LIDAR would be accurate enough to replace photogrammetry for the collection of surface terrain information. Currently, available LIDAR for which vendors state accuracies of 15 centimeters RMSE are outside the accuracies achieved by photogrammetry for final design, which are presented in Table 1. Several research projects have independently examined the elevation accuracy of LIDAR data, producing mixed results (Shrestha, et. al. 2000, Huising and Pereira, 1998, Pereira and Janssen, 1999, Berg, and Ferguson 2000, Pereira and Wicherson, 1999, Wolf, Eadie and Kyzer, 2000). Table 2 presents the results of this research. Results of these past studies suggest that in some circumstances, LIDAR under typical field conditions does not perform as well as under the optimal conditions for which LIDAR data are tested and reported. This leads to the conclusion that LIDAR is not currently capable of serving as a stand-alone form of terrain data collection for location and design activities. An additional limitation to LIDAR, aside from elevation accuracy, is the inability to produce additional mapping products, such as breaklines. This further limits the ability of the LIDAR product to be the sole terrain model used for final location and design activities.

| **Photo Scale** | **Horizontal** | **Vertical** |
|---|---|---|
| 1”=250’ | 1.25 feet | 0.30 feet (9 cm) |
| 1”=333’ | 1.25 feet | 0.30 feet (9 cm) |
| 1”=500’ | 2.5 feet | 0.50 feet (15 cm) |
| 1”=1000’ | 5.0 feet | 1.00 feet (30 cm) |

Table 1. Accuracies of Photogrammetry Products for Various Scales (USGS)

| **Application** | **Vegetation** | **Vertical Accuracy (cm RMSE)** |
|---|---|---|
| Road Planning (Pereira and Janssen, 1999) | Leaf-Off | 8 to 15 (flat terrain),<br>25 to 38 (sloped terrain) |
| Highway Mapping (Shrestha, et. al. 2000) | Leaf-Off | 6 to 10 (roadway) |
| Coastal, River Management (Huising and Pereira, 1998) | Leaf-Off | 18 to 22 (beaches),<br>40 to 61 (sand dunes),<br>7 (flat and sloped terrain, low grass) |
| Flood Zone Management (Pereira and Wicherson 1999) | Leaf-Off | 7 to 14 (Flat areas) |
| Archeological Mapping (Wolf, Eadie and Kyzer 2000) | Leaf-Off | 8 to 22 (Prairie grassland) |
| Highway Engineering (Berg, and Ferguson 2000) | Leaf-On | 3 to 100 (Flat grass areas, ditches, rock cuts) * Direct comparison to GPS derived DTM |

Table 2. Evaluations of LIDAR Accuracy

LIDAR still may play an important role in the highway location process as it can be collected and processed much more rapidly for large areas than any of the conventional methods. Even though elevations are not as accurate as photogrammetry and cannot be used for final design, LIDAR can be used in the early stages of initial route location and formulation of alternatives. LIDAR can be collected fairly rapidly and cheaply for large areas, allowing alternatives to be investigated early in the process. This allows steps to mitigate environmental or property considerations to be taken much earlier. Once a final alignment is selected, photogrammetry can be used to produce final surface terrain information for final design. Photogrammetry quality aerial photographs can be staged when environmental conditions are favorable either for the entire area to allow unexpected changes in the final alignment to be addressed rapidly or only for the final alignment corridor. Consequently, the most promising potential of LIDAR in the process is as a supplement to photogrammetry. This paper discusses the use of LIDAR in the early stages of the location and design process to expedite planning and evaluation of alternatives prior to final design.

## AN INTEGRATED APPROACH

It is possible that advanced methods of surface mapping (LIDAR) and digital photography may be used for preliminary planning and location issues, limiting expensive and time consuming photogrammetric work to the final alignment corridor. LIDAR developed terrain products and digital imagery are of sufficient accuracy for planning activities, so it is possible for products to be delivered to planners and designers more rapidly and at lower costs.

Once final alignment decisions are made, photogrammetric control and processing can be limited to the final alignment corridor. At this scale, photogrammetric work could be completed in shorter timeframe at reduced cost. The following sections describe the production of terrain data for a typical highway location process.

## Existing Process

Once a study corridor has been defined, photogrammetric data are ordered and a series of steps spanning months, or even years, is initiated. Figure 1 shows a schematic of the process. The first task of photogrammetric mapping is the placement of photo control. In some cases, existing features may be used (manholes, etc.), while in other cases, actual targets (fabric X's) are placed in the field. Photo control serves as a known location (XY) for which aerial photos can later be georeferenced.

The next step is to fly the corridor and collect aerial photography of adequate resolution which depends on accuracy requirements for the project. Table 1 presents the accuracies for photogrammetric products produced at various scales as recommended by the USGS. Imagery is subsequently developed and scanned and converted to a digital format. Aerial triangulation then extends horizontal and/or vertical control for the measurement of angles and/or distances on overlapping photographs are related into a spatial resolution using the perspective principles of the photographs (Slama, ed. 1980).

Once aerial triangulation is completed, breaklines and masspoints can be produced. When these two products are combined together, they produce a Digital Terrain Model (DTM). The DTM is used to produce additional products, including orthophotos, contours, and Triangulated Irregular Networks (TINs) (the photogrammetric products useful to designers).

With these photogrammetric products, designers can identify a final, preferred alignment. Once the development of an alignment is approved, additional field surveys and photogrammetric work are performed to densify the existing network. This densification allows for detailed design plans (driveway intersections, inlet elevations, etc.), as well as accurate estimates of earthwork quantities, to be completed for the alignment.

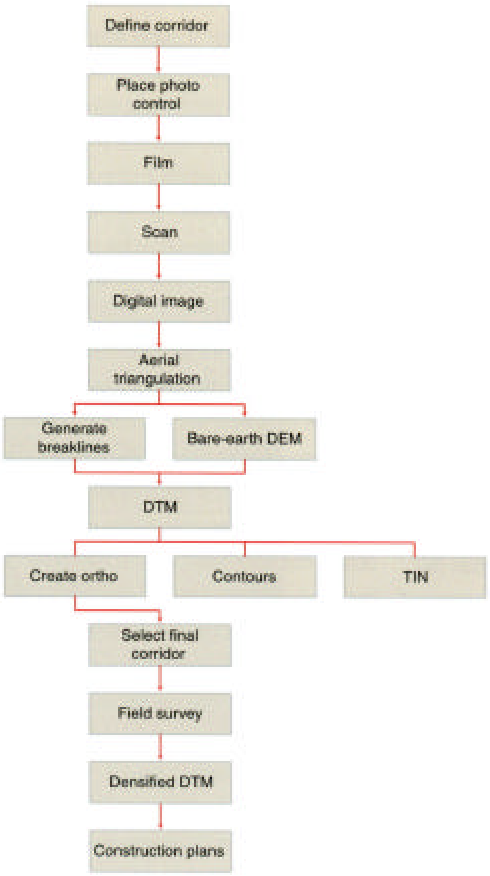

Figure 1. Photogrammetric Process

## Proposed Integration Methodology

The existing photogrammetry process requires early collection and processing of data to support final design in order to avoid delays. However, only the final design stages of project development require the accuracies provided by conventional photogrammetric processing. This presents the opportunity for use of the less accurate LIDAR terrain data in the early phases of the location process, reducing the requirement for more accurate photogrammetric (for final alignments during later phases). With LIDAR, terrain data are available earlier in the process, allowing alignments to be identified sooner. Photogrammetry can then be produced for a limited area in a shorter timeframe than would be the case for a large-scale corridor. Figure 2 illustrates the proposed methodology for using LIDAR data in the photogrammetric mapping process.

The recommended method for LIDAR integration begins by defining a large area corridor, up to several miles wide in environmentally sensitive areas, for data collection. LIDAR data, as well as supporting GPS control points, would then be collected and processed. Aerial photography (either digital or hard copy) of sufficient resolution for producing high accuracy photogrammetry products are also collected at this time. Since the aerial photography is not a major project expense, it can be collected when possible for the entire area. Collection of aerial imagery, when feasible, early in the process also facilitates creating photogrammetric data for other areas should final alignment plans change later in the process. Alternatively, lower resolution images can be collected concurrently with LIDAR and then aerial images for photogrammetry taken once a final alignment is selected and environmental conditions permit.

Once LIDAR data have been processed, they can be used as an input into the aerial triangulation process for the previously collected imagery. Triangulated imagery can then be used to produce breaklines. At the same time, the LIDAR point data can be filtered and refined further to produce a bare earth Digital Elevation Model (DEM). When combined with the breaklines produced by aerial triangulation, these products would form a planning level DTM. This DTM can then be used to produce orthophotos, contours and TINs as necessary. While the DTM and its resulting products are not of the quality necessary for final design work, they do meet the needs of designers in producing and evaluating alignment alternatives, as well as selecting a final alignment.

With the selection of a final alignment, work on final design plans can begin. Such plans require highly accurate terrain information, thus, photogrammetric mapping would be utilized. Photogrammetric data can then be produced only for the final alignment area using the previously collected aerial imagery. This results in significant time savings, as only a small area of photogrammetric mapping would be required as opposed to the large area that would be required for production before final alignment selection.

The mapping of the narrow area corridor would begin with aerial triangulation of imagery only within the corridor limits. This would allow the production of additional breaklines, as needed, as well as a densified DTM for the localized area of the alignment. With these data, final construction plan, including geometric designs and earthwork quantities could then be produced.

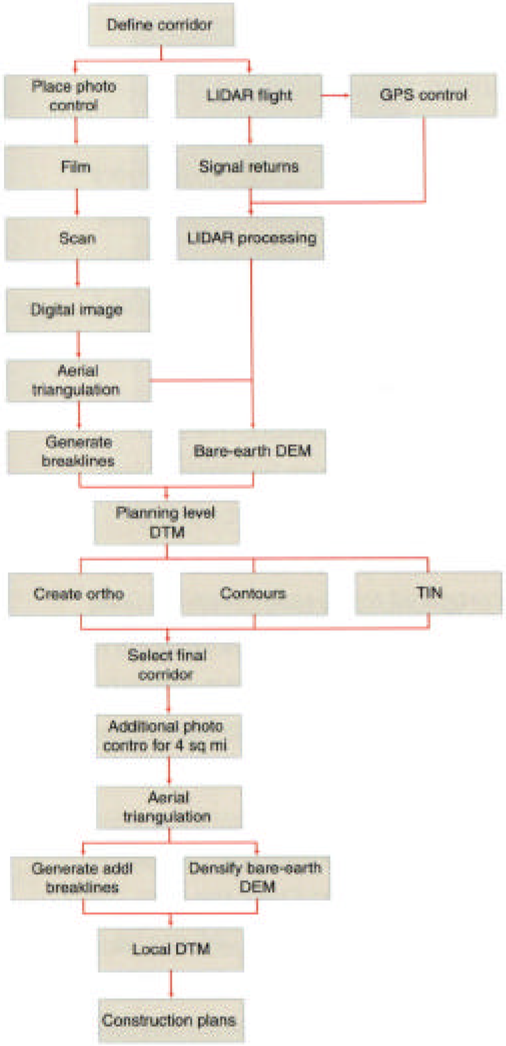

Figure 2. LIDAR Supplement Photogrammetry

## Estimated Time and Cost Savings

Two projects were examined to evaluate the use of LIDAR data compared to photogrammetry for location and design. The first project, which has been completed, involved data collection for a 10 square mile corridor. 598 hours were required to produce LIDAR mapping products, while 2,670 hours were required to produce photogrammetric products, representing a savings of 71% (Veneziano, 2002).

The second project, currently in progress, involved the collection of LIDAR data along a 46 mile corridor. The recommended procedure of obtaining LIDAR data for the entire wide corridor, followed by detailed, reduced-scale production of photogrammetry is being followed. Iowa DOT staff estimated two years would be required (calendar time) to produce high accuracy photogrammetric products for the entire corridor (Iowa DOT, 2002). However, with LIDAR, the time to collect, produce and deliver terrain data for preliminary location was only five months. Detailed photogrammetric mapping for the final alignment is estimated to require only an additional eight months. The LIDAR/photogrammetry method was estimated to take thirteen months to produce the necessary terrain data compared to twenty-four months for a photogrammetry-only product, a net savings of eleven months in the development of the project.

Terrain products are on the critical path for project planning, location and final design. Because LIDAR can be collected with fewer seasonal and atmospheric constraints than aerial photogrammetry, project timelines are more flexible. Because terrain products over a wide area can be available sooner, planners and environmental specialists, as well as conceptual designers have more flexibility to get their work done. Figure 3 shows a typical project development project timeline (optimized as part of an Iowa DOT department wide effort to streamline project development). Activities that may be accelerated with use of airborne laser swath mapping are indicated on the figure.

Financially, it was estimated that photogrammetric mapping for the corridor would cost $500,000, while the LIDAR data collection cost an actual $150,000. Additional photogrammetric work for narrowly defined alignment corridors will cost an estimated $100,000. The result is an estimated total mapping cost of $250,000, a savings of 50% over the estimated cost of photogrammetric mapping. It should be noted that the times and costs presented here were estimates of the potential savings – final figures are expected to be available upon completion of the project in 2003.

## SUMMARY

While contemporary LIDAR data may be incapable of completely replacing photogrammetric data in the final design of alignments, it can expedite the location process. Terrain information is available to designers sooner. Initial terrain data collection is not as dependent on environmental conditions (sun angle, cloud cover), since LIDAR is not affected by such conditions in the same manner as photogrammetry. Aerial imagery for the study area can then be collected when feasible. This would allow data to be collected more days throughout the year. The increased availability of data would allow terrain to be analyzed earlier in the location process, allowing issues to be identified and addressed at an earlier time. While direct time and cost savings could approach or exceed fifty percent, acceleration of project completion and/or additional time and resources available for careful consideration of social and environmental consequences and their potential mitigation is likely to produce more significant returns on investment in the new technology.

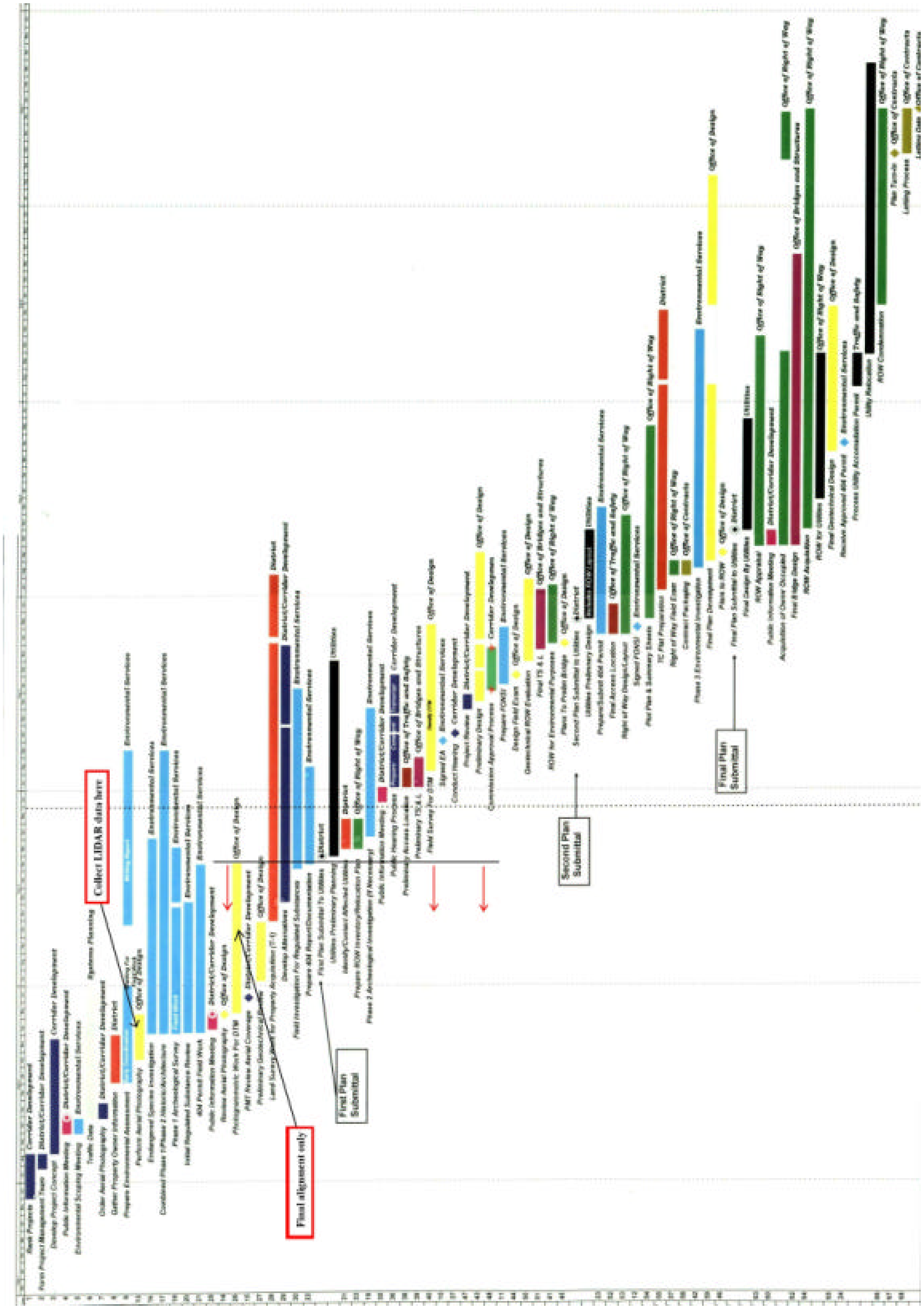

Figure 3. LIDAR Potential to Accelerate Project Development (Iowa DOT 2001)

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