OPTIMISING TRANSMISSION LINE ROUTE ALIGNMENT DESIGN USING AIRBORNE LIDAR AND IMAGERY DATA AND PLS-CADD SOFTWARE FOR COST EFFECTIVE TOWER SPOTTING

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ABSTRACT

Conventional transmission line route design in Malaysia consists of “charting” techniques performed by land surveyors supervised by transmission line engineers. An initial route is selected using 30m contour and land use maps. For this initial route, a land surveyor performs a detailed survey of the 60m width line and integrates this with comprehensive cadastral information. However, after the detailed survey, often many parts of the initial route will be found to be unfeasible due to site features which are not shown on 30m contour and land use maps. Thus, the transmission line route will be subject to multiple deviations at site leading to increased costs and time for construction.

However, for the 275 kV Ulu Jelai – Tapah & 500kV Tapah – Bentong Transmission Line Project, airborne LiDAR and Digital Imagery survey of the proposed route at 500m width and Tower Spotting using PLS-CADD was carried out to minimize these deviations and provide for a more optimised design. These allowed transmission line engineers to model the construction costs of several alignments options effectively and efficiently. The final route selected would therefore have minimized deviations, construction costs and time. For this project, it was found that 29% of the proposed route derived from conventional transmission line route design required deviation but LiDAR and PLS-CADD could have avoided this.

LiDAR is a modern remote sensing technique that allows for fast, accurate and dense topographical mapping. It was especially beneficial in the dense forest and steep terrain of this project, which can be very difficult for land surveyors to access, let alone survey. PLS-CADD is the premier overhead power line design software for the industry allowing for fast and accurate cost effective transmission line design.

INTRODUCTION

Transmission Line Route Alignment Design

For new transmission lines route alignment design, accurate terrain and features measurement is necessary to select the most feasible route technically and economically. Features such as existing transmission line catenaries, road furniture, building rooftops, etc. must be precise mapped in 3D to review their effect on a proposed new transmission line. However, these were previously not considered during route design leading to clearance violation, tower failure (due to excessive height) and other issues. As these issues were only “discovered” at site, time and cost overruns would ensue. Ideally, all issues affecting the new transmission line should be reviewed by designer before going to site and as such, should follow these important 3 stages.

The first stage is “Inventorizing” where the area between the start and end substations is mapped in detail for terrain, geography and features that may affect clearance. Airborne LiDAR is optimal for these purposes as it is able to collect large areas of highly accurate and dense topographical and features information in digital 3D format in a short time.

The second stage is “Classification” where the PLS-CADD software translates the survey data into a readable format where data points are feature coded with labels such as trees, roads, rivers, settlements, street furniture, rooftops, etc. These labels enable the software to check clearance violations during the Optimum Spotting process. The feature coded data points can be filtered in and out of the software to display certain aspects of the terrain information at different stages of the tower spotting process.

The last stage is “Optimum Spotting” where based on the highly accurate and dense data produced from above stages, studies are performed to locate the various angle point (AP) structures of the line and subsequently, the PLS-CADD software spots the various intermediate structures at optimum locations for minimisation of number and cost of towers. Several options exist where PLS-CADD allows for optimization of structures based on parameters that include the cost of the structure. PLS-CADD also considers terrain restrictions, such as marshland or expensive urban areas to spot the new transmission line. The engineer always has the option to
spot each tower manually by selecting structure locations based on his or her experience and familiarity with the selected route. **Optimum Spotting** optimizes the spotting by taking account of various inputs such as conductor type, tower type and cost, minimum safety factors, clearances, sag-tension limiting conditions, allowable wind and weight span and so on.

Thus, by fully mapping the area in detail and designing the line to enable accurate cost evaluation, the transmission line route design would be able to minimize transmission line construction costs and time.

**LiDAR**

LiDAR (Light Detection and Ranging) is an active remote sensing technique for precise distance measurement. It works by emitting a laser pulse and measuring the time for the pulse to be reflected from the target to calculate the distance. LiDAR has many applications but for transmission line survey, airborne LiDAR is most commonly used. For airborne LiDAR (Fig.1), the LiDAR scanning unit is integrated with Differential Global Positional System (DGPS) for accurate positioning and an Inertial Measurement Unit (IMU) for accurate orientation measurement. Processing the data from these 3 sensors together generates a 3D “point cloud” of the mapped area. The LiDAR system may be mounted on helicopter or fixed wing aircraft but for transmission line survey, helicopter is preferred as it is able to follow the transmission line alignment more easily.

![Diagram of integrated LiDAR scanning unit with DGPS and IMU to derive 3D point cloud of mapped area](image)

The raw 3D point cloud would then undergo ground and other features classification for analysis. Digital Terrain Models (DTM) or Bare Earth Model, Digital Elevation Models (DEM) and Contours may then be generated.

Most airborne LiDAR systems will simultaneously capture high resolution colour imagery. These would be georectified using the data from DGPS and IMU, then digitally mosaiced together. Thus the design engineers would have the classified point cloud and imagery data for full understanding of site conditions. The co-registered LiDAR data and imagery data could also be combined to produce ‘fly-through’ to facilitate visualization and analysis.

The newest development for LiDAR is the Waveform LiDAR system (Fig.2). Whereas conventional LiDAR systems capture up to 4 returns per pulse at an averaged amplitude and time, waveform LiDAR systems digitise all returns so no returns are missed and the shape of the return pulse can be further analysed for surface roughness and slope evaluation. Both conventional and Waveform LiDAR were tested for this project.
LiDAR is highly advantageous for Transmission Line route selection design as it is able to capture highly accurate and dense data at a fraction of the time and cost of land survey methods, whilst being robust against human error. The elevation accuracy of other forms of remote sensing such as satellite and aerial photogrammetry are poor in comparison and thus would only be used during macro studies. Particularly in dense forest and steep terrain areas, which encompass much of this region’s new Transmission Lines, only LiDAR is able to accurately measure ground elevations under dense forest canopy without interpolation or ground intrusion. Conventional land survey requires line-of-site survey which is problematic in such areas. Minimising ground intrusion would also be beneficial to land acquisition.

**PLS-CADD and Transmission Line Design**

Power Line Systems Computer Aided Design and Drafting (PLS-CADD) is a transmission line design program that includes all the terrain, sag-tension, loads, clearances and drafting functions necessary for the design of an entire transmission line. It supports the entire design process, from the selection of a line route through to the
production of construction documents and drawings. The Optimum Spotting module of PLS-CADD enables automatic selection of tower structure locations and types for the least cost design of a line.

PLS-CADD is the industry leader for this type of software and requires high accuracy and density elevation and features information for optimised design. Thus, LiDAR and imagery data converted to PLS-CADD format allows engineers to clearly assess the site conditions, such as catenaries of existing transmission lines, vegetation height, road furniture, etc. for optimised design.

Study Area

![Map of study area of 275kV Ulu Jelai – Tapah & 500kV Tapah – Bentong Transmission Line Project](image)

The study area consisted of two lines (Fig.3): the 60km of 275kV Double Circuit Transmission Line connecting Ulu Jelai Main Intake Substation at Ulu Jelai Renewable Hydro Power Plant and Tapah Main Intake Substation; and the 140km of 500kV Transmission Line connecting Tapah Substation to Bentong (South) Substation for future interlink of HVDC System from Sarawak to Peninsula Malaysia (Bentong). Thus, the total study area's corridor was approximately 230km long and 0.5 km wide.

The study area was divided into four parts where the first part started at Ulu Jelai Main Intake station and went across the Susu Dam within Telanok Valley, and the second part was toward the south of Ringlet Town into the mountainous forested area. The third part crossed three existing transmission lines, the 132kV Woh-Bintang line, the 132kV Woh-Kalumpang / Bidor Woh line and the 275kV Bukit Beruntung-Batu Gajah, Jor line and ended at PMU Tapah 500kV. The fourth part of the line was from PMU Tapah, crossing the outskirts of the towns of Ulu Yam and Kuala Kubu Bahru into the forest reserve and ended at PMU Bentong, (South) in Pahang.
The terrain conditions of the study area varied from flat to steep with mountainous conditions throughout most of the study area. The first part was remote village land with vegetable farms and some rubber plantations. The second part consisted of densely forested area and large commercial vegetable farmland. The third part was densely forested area, whereas the fourth part was densely forested areas mixed with rubber and oil palm plantation areas. These mountainous regions gave rise to weather conditions of low lying cloud and fog at certain times during the day, especially after 12pm. Thus, to acquire good quality airborne imagery, the data acquisition was carried out mostly in the morning (between 7am to 11am).

These terrain conditions were problematic for conventional land surveying due to difficulties in accessing the site and doing line of site survey. Satellite data is of coarse resolution and would be affected by cloud cover. However, LiDAR techniques were able to capture the highly dense and accurate data required within a short time.

DVG-Helix LiDAR and Digital Imagery system

For this project, the DVG-Helix LiDAR and digital imagery system was used. It was developed by Ground Data Solutions R&D Sdn Bhd (GDS) and its partner LiDAR Services International (LSI). The system is unique in having multiple mounting capability (is able to be mounted on several types of aircraft) and in being a modular system, which can be fitted with 4 different types of scanning laser, 3 different types of IMU, 4 different types of camera and video camera. LiDAR data was collected using two configurations of the DVG-Helix system: with a Riegl LMS Q560 Waveform scanning laser of 100 kHz pulse rate and Canon EOS 1D Mark III camera of 11 megapixels, and with a Riegl LMS Q240 of scanning laser of 30 kHz pulse rate and Canon EOS 1D Mark II camera of 8 megapixels. Both systems were installed on a Bell 206B JetRanger helicopter for acquisition.

METHODOLOGY

![Flow diagram of the project’s methodology](image)
Figure 4 provides a flow diagram of the projects methodology. Firstly, a preliminary route was selected using 30m contour and land use maps. Then, a helicopter reconnaissance of this route was carried out on 24th June 2008 date to finalise the route for the LiDAR and Digital Imagery Survey or “Inventorizing” stage.

For the LiDAR and Digital Imagery survey, the team firstly established ground reference stations to integrate the survey data to the local coordinate system. Acquisition was done on 16th May 2008 using DVG Helix in Reigl LMS Q560 Waveform configuration at 400m flying height (above ground level) and then from 24th to 28th September 2008 and from 7th to 13th October 2008 in Reigl LMS Q240 configuration at 250m flying height. During the LiDAR and Digital Imagery survey, further features were identified by transmission line engineers, who could immediately recommend alternative routings to be surveyed at little extra time and cost.

The raw data from the LiDAR sensor, DGPS and IMU were processed using dedicated in-house programs to produce the point clouds in WGS84 latitude, longitude and ellipsoidal height. This was then transformed to Rectified Skew Orthomorphic (RSO) projection with the vertical coordinates based on the adjusted Mean Sea Level (MSL) height, using the MyGeoid model (best possible national geoid model established by The Department of Surveying and Mapping Malaysia, JUPEM). The point cloud classification and contour generation were done with Microstation, TerraScan and TerraModeller software, while orthophoto mosaics were generated with AutoCad and 3D Fly-Through using ArcGIS 9.3. The final DTM, DEM and contour were submitted on 24th Oct 2008 while 3D fly through was submitted on 17th November 2008.

Then, the LiDAR and imagery data was integrated with cadastral information by land surveyors to select a final alignment for tower spotting using PLS-CADD, which was submitted on 17 November 2008. The “Classification” stage, where the data was converted to PLS-CADD format was from 9th December 2008 to 30th December 2008 date. The “Optimum Spotting” stage was from 31st December 2008 to 31st January 2009 when the final plan and profile drawings and tower spotting drawings were submitted. This process allowed for multiple alignments to be investigated with minimum costs, time and environmental damage for most cost effective design.

RESULTS

Airborne LiDAR and Digital Imagery Survey Results

Tables 1 and 2 show the average density of LiDAR points and ground (only) points and the imagery resolution achieved by the DVG Helix in its 2 configurations.

Both configurations of the DVG-Helix were shown to achieve very high LiDAR point densities: more than 4 points/m2 in jungle and clear areas. Generally, a minimum point density of 1 point/m2 is specified to allow for accurate 3D modelling of the various features, such as street lighting, existing transmission lines, etc. and vegetation for PLS-CADD analysis and thus, DVG-Helix was able to enhance this. However, it was found that the waveform Q560 scanner was able to capture smaller features more frequently and thus was preferred by the Transmission Line engineers.

For ground point density, there was a significant improvement from the conventional Q240 scanner to the waveform Q560 scanner in dense forest areas; density is increased by ten times. In clear areas, similar ground point density was accomplished by both types of scanner and thus, both scanners are capable of good topographical measurements in clear areas. With dense forest areas, however, the waveform Q560 scanner is preferable; though even the conventional Q240 scanner achieved an acceptable average ground point spacing of 5.8m for PLS-CADD analysis.

Both configurations of DVG-Helix attained 13cm pixel resolution, which was sufficient for Transmission Line engineers to review site conditions in detail. The lower flying height with lower resolution camera may have provided slightly better imagery due to being closer to the mapped area but the difference was negligible. Generally, imagery was clear and cloud-free due to careful planning of acquisition time and flying height to avoid cloud and fog conditions.
Table 1: LiDAR and Digital Imagery Data Acquisition Results: Riegl LMS Q560 Waveform (flying height 400m AGL)

<table>
<thead>
<tr>
<th>Type</th>
<th>Area</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Dense vegetation</td>
<td>Clear area</td>
</tr>
<tr>
<td>Average LiDAR points density (All points)</td>
<td>6.41 pts/m²</td>
<td>4.44 pts/m²</td>
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<tr>
<td>Average LiDAR points density (Ground only)</td>
<td>0.31 pts/m²</td>
<td>3.61 pts/m²</td>
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<tr>
<td>Average points spacing</td>
<td>0.4 m</td>
<td>0.5 m</td>
</tr>
<tr>
<td>Average ground points spacing</td>
<td>1.8 m</td>
<td>0.5 m</td>
</tr>
<tr>
<td>Average Imagery resolution</td>
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<td>0.13 m</td>
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Table 2: LiDAR and Digital Imagery Data Acquisition Results: Riegl LMS Q240 (flying height of 240m AGL)

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<thead>
<tr>
<th>Type</th>
<th>Area</th>
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<tbody>
<tr>
<td></td>
<td>Dense vegetation</td>
<td>Clear area</td>
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<tr>
<td>Average LiDAR points density (All points)</td>
<td>6.72 pts/m²</td>
<td>4.75 pts/m²</td>
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<tr>
<td>Average LiDAR point-s density (Ground only)</td>
<td>0.03 pts/m²</td>
<td>2.42 pts/m²</td>
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<tr>
<td>Average points spacing</td>
<td>0.4 m</td>
<td>0.46 m</td>
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<tr>
<td>Average ground points spacing</td>
<td>5.8 m</td>
<td>0.64 m</td>
</tr>
<tr>
<td>Average Image resolution</td>
<td></td>
<td>0.13 m</td>
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**Tower Spotting Results**

The final route selected by land surveyors using conventional “charting” methods produced 44 Angle Points (APs) for the 275kV line and 56 APs for the 500kV line. However, PLSCADD analysis showed that 18 APs for 275 kV line and 11 APs for 500kV line were unsuitable. Thus, approximately 29% of the line would require deviation to allow for a more cost effective design. In previous projects, these problematic APs would only be identified at site leading to late and expensive deviation, compared to this project where they are identified quickly by transmission line engineers and easily rectified without having to re-survey.

The APs were unsuitable as they did not appropriately manage one or more of the following: river crossing, existing transmission line crossing, hilly terrain and ROW/cadastral issues. More detailed information can be found in Table 3 below. The following 3 case studies explain the various types of unsuitable APs and their solutions.
Table 3: Summary of Problematic APs chosen using conventional “charting” methods and their solutions.

<table>
<thead>
<tr>
<th>Line Description</th>
<th>No.</th>
<th>Angle Points</th>
<th>Issues</th>
<th>Solution</th>
</tr>
</thead>
</table>
| 275kV Double Circuit Transmission Line Ulu Jelai Main Intake Substation to Tapah Main Intake Substation | 1. | AP 2 to AP 4 | Hilly terrain:  
• AP 2 was located at a higher point of the terrain  
• AP 3 was located in a valley  
• AP 4 was located at a higher point of the terrain | Relocated the APs at higher points of the terrain in order to avoid the usage of special towers. |
| | 2. | AP 4 to AP 6 | Hilly terrain:  
• AP 4 was located at a higher point of the terrain  
• AP 5 & AP 6 were located in a valley | Introduced additional APs (AP 5a & 5b) to re-route the alignment at almost same levels in order to avoid the usage of special towers and optimize the tower strength. |
| | 3. | AP 9 to AP 12 | River crossing:  
• AP 11 was initially located in the river (during desktop study using 30m contour maps) | Relocated AP 9 to AP 12 to re-route the alignment in order to cross the river at appropriate angle. |
| | 4. | AP 14 to AP 16 | Existing transmission line crossing:  
• AP 15 & AP 16 were located at points where the proposed line had difficulties to have safe vertical clearance with the existing transmission line. | Relocated AP 14 to AP 16 to re-route the alignment in order to cross the existing transmission line with the safe vertical clearance required by TNB. |
| | 5. | AP 30 to AP 31 | River crossing:  
• AP 30 & AP 31 were initially located at the river bank (during desktop study using 30m contour maps) | Relocated AP 30 & AP 31 away from the river bank in order to cross the river at appropriate angle. |
| | 6. | AP 33 to AP 34 | Existing transmission line crossing:  
• AP 33 & AP 34 were located at points where the proposed line had to cross 4 numbers of existing transmission line. | Relocated AP 33 to AP 34 to re-route the alignment in order to cross the existing transmission line with the safe vertical clearance required by TNB. |
<table>
<thead>
<tr>
<th>Line Description</th>
<th>No.</th>
<th>Angle Points</th>
<th>Issues</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.</td>
<td>AP 38 to AP 39</td>
<td>Existing transmission line crossing: • AP 38 &amp; AP 39 were located at points where the proposed line had to cross 1 existing transmission line.</td>
<td>Relocated AP 38 to AP 39 to re-route the alignment in order to cross the existing transmission line with the safe vertical clearance required by TNB.</td>
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<tr>
<td>8.</td>
<td>AP 3 to AP 5</td>
<td>Existing transmission line crossing: • AP 3 to AP 5 were located at points where the proposed line had to cross 4 numbers of existing transmission line.</td>
<td>Relocated AP 3 to AP 5 to re-route the alignment in order to cross the existing transmission line complying with the safe vertical clearance required by TNB and good tower position.</td>
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<td>9.</td>
<td>AP 13 to AP 14</td>
<td>Hilly terrain: • AP 13 was located in a valley • AP 14 was located at a higher point of the terrain</td>
<td>Introduced additional AP (AP 13a) to re-route the alignment at almost same levels in order to avoid the usage of special towers and optimize the tower strength.</td>
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<td>10.</td>
<td>AP 18 to AP 19</td>
<td>Hilly terrain: • AP 18 &amp; AP 19 were located in a valley • The terrain between the APs was highland, thus causing the intermediate towers to fail badly in structural strength.</td>
<td>Relocated the APs at the most suitable location of the hilly terrain in order to minimize the usage of special towers.</td>
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<td>11.</td>
<td>AP 24 to AP 25</td>
<td>Land acquisition / ROW issue: • Initially the proposed line crosses the boundary of two Hydro Power Station namely Stesen Janakuasa WOH and Stesen Janakuasa JOR.</td>
<td>Introduced additional APs (AP 24a, 24b &amp; 24c) to divert the proposed alignment from entering the boundary of the power station at the most suitable locations using the information provided by LiDAR. Conventional method would have needed re-survey.</td>
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<td>12.</td>
<td>AP 45 to AP 46</td>
<td>Existing transmission line crossing: • AP 45 to AP 46 were located at points where the proposed line had to cross 2 numbers of existing transmission line.</td>
<td>Introduced additional APs (AP 45a, 45b &amp; 45c) to re-route the alignment in order to cross the existing transmission line with the safe vertical clearance required by TNB.</td>
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Case Study 1: River Crossing

AP11 was initially selected using conventional “charting” methods during the desktop study. As can be seen from Figure 5 below, AP11 was found during the ground and LiDAR survey to be placed within a river. Using PLSCADD and LiDAR and imagery data, transmission line engineers were able to quickly and easily spot the new AP11 to avoid a difficult river crossing. Figure 6 illustrates the old and new APs in 3D view using the terrain model created from the LiDAR data. With this model, issues of clearance, elevation, etc. are easily managed for fast and effortless AP selection.

Figure 5: Plan View of conventionally selected AP11 and new LiDAR and PLS CADD selected AP11
Case Study 2: Transmission Line Crossing

One of the main advantages of LiDAR is its ability to accurately map in 3D any features that may affect a proposed Transmission Line. LiDAR is the only method of precisely surveying the catenaries of existing Transmission Lines. This is crucial to tower spotting of the new Transmission Line to ensure that the crossings occur at the most technically advantageous and cost effective point. This is generally the lowest point of the existing Transmission Line catenaries so as to minimize the height requirement for clearance of the new Transmission Line and thus, its towers.

Figure 7 shows the plan view of the existing 132kV transmission line and the proposed new 275kV transmission tower positioned using conventional methods. Here, the conventionally proposed new tower has been placed on one of the conductors of the existing transmission line, which is very awkward to build due to height and space limitations. Figure 8 shows the same conventionally selected crossing in 3D view where new transmission line has a clearance violation with the top conductor of the existing 132kV transmission line.
Figure 7: Plan view of Existing 132kV Transmission Line and conventionally selected new 275kV Transmission Tower

Figure 8: 3D View of conventionally selected new 275kV Transmission Line Tower and the existing 132kV top conductor height at crossing
Case Study 3: Hilly Terrain

The 3D digital format of LiDAR data is especially invaluable to the understanding of the terrain of hilly areas. In comparison, the plan view nature of land survey data does not lend itself to precise representation or comprehension of terrain conditions. Thus, conventional AP selection, which does not use LiDAR data, can easily lead to APs in wrong positions such as in valleys, resulting in excessive tower heights. In these cases, special towers may be built, but these are undesirable due to their high cost and construction difficulties. Towers are also more prone to structural failure.

However, the high accuracy and density of terrain data from LiDAR allows for high definition 3D viewing of the terrain, leading to quick and easy tower spotting to elevations and positions that do not require excessive tower heights (ie. Special Towers). In many cases, the shift of position is of the magnitude of 10s of metres but has the implication of cost savings of millions of ringgit.

Figure 9 to 13 illustrate in various PLS-CADD views, the unsuitability of the conventionally selected location of AP27 in a valley, which places adjacent towers on the hilltops. To ensure that there are no clearance violations in that terrain, the tower at AP27 would have to be raised to excessive height (+24m), necessitating the use of a special tower. Simultaneously, there is failure due to excessive structural load in adjacent towers due to poor positioning in hilly terrain.

Figure 9: PLS-CADD Plan View of Towers Spotting around the conventionally selected AP27, which was unsuitably located in a valley, creating the need for a special tower and structural failure in adjacent towers
Figure 10: PLS-CADD Profile View of Towers Spotting around the conventionally selected AP27, which was unsuitably located in a valley, creating the need for a special tower and structural failure in adjacent towers.

Figure 11: View of Tower Spotting around the conventionally selected AP27, which was unsuitably located in a valley, creating the need for a special tower and structural failure in adjacent towers.
However, the use of the 500m width corridor of LiDAR data and PLS-CADD, is able to simply resolve these problems by moving AP27 to a more appropriate location, which does not require excessive height or engender excessive structural loads. Convention methods do not easily lend themselves to this as usually, the topographical data will be from 30m contour maps or land survey data of 30m to 100m width only. Any deviation would require re-survey and corresponding delay and additional costs. However, the 500m width...
A corridor of LiDAR data is able to accommodate most relocations of APs comfortably without the need for extra time or cost.

Figure 14 to 18 demonstrate the PLS-CADD and LiDAR corrected AP27 solution. AP27 now only requires a normal tower (+15m) and adjacent towers are within the allowable structural strength.
Figure 16: 3D View of Corrected AP27 at Hilly Terrain

New AP27 – optimum location

Initial AP27 – at the valley

No failing towers

Figure 17: Structure Usage Report 1 of corrected AP27 at hilly terrain
In fact, the Transmission Line designers may proposed several alternative AP positions and Transmission Line routes; but the wide corridor of high resolution and accuracy topographical and imagery data from LiDAR coupled with PLS-CADD, allows for very quick analysis to decide on the most cost effective design. This is far superior to conventional methods where frequently, no construction cost evaluation is done.

DISCUSSION

The conventional “charting” method of transmission line route design, which uses 30m contour, cadastral and other macro data to decide on an alignment and then has land surveyors map a 60m width of the route, produced an alignment of which 29% would be problematic and/or expensive to construct. In previous cases, some of these issues would be identified at site and the land surveyors and engineers would then try to solve the problem by reviewing the desk study information and re-surveying the new alignment at 60m width. However, this often would be repeated several times before an acceptable alignment is found, leading to lengthy delays and excessive additional costs. Some issues would not be identified till the design stage which is frequently after the survey is completed and the land acquisition has started so the design engineers would not be able to propose a deviation to resolve the issue but generally have to use expensive engineering solutions instead.

However, Table 2 shows how easily and quickly Airborne LiDAR and Digital Imagery survey with PLS-CADD is able to identify and resolve any problems in the transmission line alignment. The new alignment drawings were produced within days, minimising delays and project cost overruns, compared to traditional methods, which would have required multiple re-surveys taking months and increasing costs. Traditional charting methods do not do a cost evaluation of the line compared to LiDAR and PLS-CADD methods which fully calculate construction costs and optimise the design by minimising number of towers and removing the requirement for special towers.

While transmission line route alignment design still requires land surveyors to map, monument and mark out the proposed route, this project has clearly shown the advantages of the Airborne LiDAR and Digital Imagery survey with PLS-CADD technique: survey and project time and costs are minimized by reducing deviations
while a cheaper and more technically feasible transmission line to construct is realised. Changes can be implemented and Transmission Line drawings produced more quickly as all the data is readily available in digital format. GDS’s DVG-Helix was able to map a 500 m width corridor of the alignment in less than 2 weeks of flying for both topography and digital imagery compared to conventional land survey which would mapped only a 60m width corridor and taken months. Also, the digital waveform scanner with high infrared laser pulse repetition rates up to 100 kHz was able to measure the catenaries of the thinnest transmission lines. Besides that, the LiDAR point density was more than 4 points per m² compared to conventional survey cross sections at 50m intervals. DVG-Helix performed exceptionally well that it was the only solution considered for the new route survey as it allowed for a change in alignment with little change in the construction schedule.

CONCLUSION
Airborne LiDAR and Digital Imagery survey with Tower Spotting using PLS-CADD proved to be more effective and efficient than conventional route alignment methods used in Malaysia, resulting in less cost and less towers in shorter time for transmission line route alignment designs. Deviations were minimized and changes to the route and drawings produced very quickly compared to conventional methods. Though land surveyors would still be required to map, monument and mark out the proposed route, Airborne LiDAR and Digital Imagery survey with Tower Spotting using PLS-CADD techniques should constitute all good transmission line route alignment design as the cost and time benefits to the projects are clear.

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