Land Evaluation for Oil Palm Cultivation using Geospatial Information Technologies

Nordiana, A A*; Wahid, O*; Esnan, A G*; Zaki, A*; Tarmizi, A M*; Zulkifli, H* and Norman, K*

ABSTRACT

Land evaluation is the process of assessing the characteristics of a given piece of land to determine its suitability and viability for development. For oil palm cultivation, land development involves planning, land clearing, road and drainage networks development and oil palm planting. This article reports the results of land evaluation carried out in Sungai Asap, Belaga, Sarawak to investigate the effectiveness of geographic information system (GIS), global positioning system (GPS) and remote sensing (RS) in evaluating whether a land is suitable for oil palm cultivation. Results of the study indicated that only 61.8% of the study area was suitable to be cultivated with oil palm. The rest of the area was unsuitable because of steepness, accessibility and allocation for buffer zones. SPOT (Système Pour d’Observation de la Terre 5) satellite data was able to provide preliminary information of landform, land use and infrastructures of the evaluated land. GPS and GIS employed in this project were able to precisely track and collect ground data. The technologies could predetermine length and density of roads and terraces, and the number of planting points. The information was manipulated to produce land assessment report and very useful for preparation of budgets and contracts for plantation development.

INTRODUCTION

The advances made in geospatial information technologies such as global positioning system (GPS) and geographic information system (GIS) have influenced plantation managements to be more inclined towards using the computer support systems in decision-making. Technologies such as GPS and GIS have been used to establish different levels of oil palm databases. Xaviar et al. (2001) reported that GPS has been used for area mapping and positioning, while Ooi and Tey (1998; 2001) suggested GPS for navigation work. Many researchers (Tey et al., 1997; Sugih et al., 1998; Chew and Annuar, 2000) have reported using GPS for mapping and surveying of oil palm plantations to produce precise digital maps. They found that GPS is capable of producing cheaper, more accurate and more rapid digital maps compared to the conventional land surveying and mapping methods. The accuracy of GPS mapping depends on the type of GPS used, the way mapping is carried out and the data pro-

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ABSTRAK

cessing techniques used to produce the maps. Wahid and Tarmizi (2001) in their study found most of the GPS inaccuracies can be corrected using a differential correction technique.

Remotely sensed (RS) imagery has been suggested as the most useful data source for measuring and mapping the land use quantitatively at landscape scale (Hudak and Wessman, 1998). Compared to the traditional survey methods, RS is more accurate, timely and cost-effective. It is the only practical way to obtain data from inaccessible areas. RS is also useful for identifying land characteristics which are invisible from the ground survey. RS is the cheapest and most rapid method of constructing base maps of the land compared to the conventional method of surveying. Methods of RS include aerial photography, radar, and satellite imaging. Wahid et al. (2005; 2010) found that satellite imaging data of the Landsat Thematic Mapper and Système Pour d’Observation de la Terre (SPOT), respectively have been successfully used to identify oil palm-growing areas and to determine the total oil palm area on peatland.

GIS and GPS technologies have been used by oil palm plantation managements to collect and manipulate the collected data for decision-making. Fairhurst et al. (2000) suggested that GIS can be an important management tool in oil palm plantations if the agronomic and accumulated field survey data are combined in an agronomic database. Sugih et al. (1996) reported that PT Salim Indoplantation has used GIS and GPS for compiling resources inventory, monitoring of estate performance, producing of map, analysing of fresh fruit bunch (FFB) production, monitoring of pest attacks, and for modelling of flood hazard. GIS and GPS also have been used for monitoring tractors movement in the oil palm plantation by Ooi and Tey (1998; 2001). A more recent study by Nedalet al. (2007), has successfully integrated RS and GIS to predict the potential use of land on the basis of its attributes and identified the best land management practice for sound land use planning.

We utilised GPS, RS and GIS technologies to evaluate a land for oil palm development. In this article, we report our study in Belaga, Sarawak.

**EXPERIMENTAL**

**Study Site**

This study was carried out in 2009 in Sungai Asap, Belaga, Sarawak (Figure 1). It is situated at north-east of Bintulu, on the way to the Bakun Dam. The geographical location of the area is located at upper left: 3° 1’ 7.58” N, 113° 54’ 33.67” E and lower right: 2° 57’ 59.84” N, 114° 2’ 0.28” E. The total area of the study site is 970.36 ha. The area is hilly and the highest elevation is 700 m above sea level.

**Satellite Image**

SPOT-5 images were used in this study and the raw images were in tagged image format (TIFF). The data was suitable for image interpretation and visual analysis of land use and land cover. Two different data scenes were used: multispectral image (four bands) with 10 m spatial resolution and panchromatic image (single band) with 2.5 m spatial resolution. Both scenes were projected in world geodetic system (WGS) 1984 projection before it was used for further analysis. SPOT-5 image characteristics are shown in Table 1.

**Topographic Map**

Topography information was extracted from topographic map sheet No. 192 of DNMM5201 series. The information was based on 30 m contour interval and with referral scale of 1:50 000. Other supporting data used was the site survey map plotted in 1:15 000 referral scales and was dated on 9 April 2008.

**Equipment**

Differential global positioning system (DGPS) and hand-held GPS were used for ground truthing and tracking respectively. The DGPS (Hemisphere R120) was a real time correction GPS using Omnistar subscription signal and the planimetry accuracy was in sub-meter. The DGPS was used to determine land boundary and to develop a digital terrain model (DTM) of the study area. The hand-held GPS (Garmin GPShmap 60CSx) with accuracy of 5 m error was mainly used for demarcating the land use and other features in the study area.

**Software**

The Erdas Imagine 9.1 was used to process and analyse the satellite images. ESRI (2008) has demonstrated the use of ArcGIS 9.2 with 3D analyst extension for mapping and analysing the land use and land cover area.

**Satellite image pre-processing.**

**a. Data conversion**

Pre-processing involved data type conversion, spatial resolution merge, projection conversion and image subset. Raw satellite image in TIFF format was converted into Erdas Imagine standard format.
**b. Satellite image resolution merging**

After data conversion, satellite image resolution of the multispectral images (10 m resolution) and panchromatic image (2.5 m resolution) was merged. The output was multispectral image with 2.5 m spatial resolution. The process was carried out using Image Interpreter, Spatial Enhancement and Resolution Merge Function of the Erdas Imagine 9.

**c. Satellite image reprojection**

For further processing, original projection of SPOT-5 image, WGS 1984 was converted into local projection of Sarawak, Borneo Rectified Skew Orthomorphic (BRSO). The reprojection process was carried out using Erdas Imaging 9.1 and the BRSO projection was available in the software. *Figure 2* shows the SPOT image of the study area in BRSO (top) and WGS 1984 (bottom) projection. The BRSO image was shifted to the left when reprojection process was completed.

**TABLE 1. SPOT-5 IMAGE CHARACTERISTICS**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>SPOT-5 Imagery # 1</th>
<th>SPOT-5 Imagery # 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor</td>
<td>High resolution geometry (HRG) &amp; high resolution stereo (HRS)</td>
<td>High resolution geometry (HRG) &amp; high resolution stereo (HRS)</td>
</tr>
<tr>
<td>Scene ID</td>
<td>52953440708110303512J</td>
<td>5295340708110303492T</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>10 m</td>
<td>2.5 m</td>
</tr>
<tr>
<td>Spectral band</td>
<td>4 Bands (multispectral)</td>
<td>1 Band (panchromatic)</td>
</tr>
<tr>
<td>Path/row</td>
<td>295/344</td>
<td></td>
</tr>
<tr>
<td>Receiving station</td>
<td>MACRES Ground Receiving Station (MGRS)</td>
<td></td>
</tr>
<tr>
<td>Acquisition date</td>
<td>11 August 2007</td>
<td></td>
</tr>
</tbody>
</table>
d. Satellite image subset

The image was subset or cropped into specific study area. The process reduced size of the image and improved time of processing and analysing of the image. The subset process was carried out using Erdas Imagine 9.

Contour and 3D Analysis

Figure 3 illustrates the 30 m contour interval that was extracted from topography map. The 3D analyst tool in the ArcGIS 9.2 was used to analyse the topography, slope and land surface orientation of the study area.

The contour lines were used to create DTM in raster format using Erdas Imagine 9.1 software. DTM was a digital representation of ground surface topography and also commonly known as digital elevation model (DEM). DTM is the basis of preliminary investigation survey and visual interpretation of land topography. The elevation values were extracted from each contour line in vector format using the Topographic Analysis, Create Surface and Surfacing Tool function of Erdas Imagine 9.1. The surfacing method used in transformation was the linear rubber sheeting and the output was in raster format with cell size of 10. The DTM output is shown in Figure 4. The darker areas represented low land or lower elevation. White or brighter areas represented high land or higher elevation.

Ground Truthing

The purpose of ground truthing was to collect ground control points (GCP) for satellite image geometric correction, demarcate the actual study area boundary and define blocks boundaries based on the preliminary designed block map.

The 30 m contour was not detailed enough to sufficiently describe the terrain and landscape of the study area. The GPS levelling method was used to improve the existing DTM. The GPS levelling was carried out using hand-held GPS, where the spot height was captured around the study area at different elevation. As shown in Figure 5, the spot height points were derived directly from the track log of the hand-held GPS.

Post-processing

Post-processing was a final process for raw input data before further analysis can be done. This process involved mainly geometric correction, image classification and ortho-rectification.

Geometric correction. RS data was usually spatially distorted due to satellite positioning on its orbit, earth rotation during the image recorded and
some other errors. Kardoulas et al. (1996) reported that geometric correction process was performed to transform the image to match a map projection. It was done by referring the satellite image by point to point on topography map or using GCP as knowledge based on the geographical coordinates to correct the geometry of the image. The geometric correction process was carried out using Geo-referencing tools of ArcGIS 9.2. Root Mean Square Error (RMSE) was used to measure the differences between values predicted by a model or an estimator and the values actually observed from the thing being modelled or estimated. The lower value of RMSE shows the polynomial model is accurate, and probability of error in measurement is around the RMSE values.

Creating digital terrain model (DTM).

a. DTM interpolation

The DTM was created using GPS levelling method due to lack of surface detail information from other topography data. The spot height data was surveyed all over the study area using handheld GPS and the data was then downloaded into computer for further processing and analysing. The track log data was converted into shapefile format and the terrain data was processed and analysed (Raster Interpolation Function) using 3D analyst tools of ArcGIS 9.2.

b. DTM accuracy assessment

The accuracy assessment of DTM required comparison of DTM created from GPS levelling as tested data to DTM from topography map as reference data. The analysis determined the pattern of deviation between the two sets of elevation data to give statistical expression of accuracy, such as standard deviation, means and RMSE. The accuracy of the tested data in this study was determined using the RMSE value (Robinson, 1994; Smith et al., 2003; Weibel and Heller, 1991; Carla et al., 1997).

Figure 6 shows the relationship between the two sets of elevation data that were analysed using regression model. The linear regression analysis carried out indicated that the R-squared value was 0.792. A study by Salkind (2000) showed that R-squared value of 0.8 – 1.0 is very strong and perfect association of correlation between the variables. Thus, in this study, it indicated very strong correlation as 79% of the DTM from topography map was explained by the DTM derived from GPS.

RMSE indicates the dispersion of frequency distribution of deviation between the reference elevation data (topographic map data) and tested elevation data (GPS levelling data). The calculated RMSE value for this regression model was 13.3. This value showed the probability error of elevation reading from the tested elevation data was 13.3 m compared to the reference elevation data. The elevation data of the DTM created by GPS levelling method was corrected using the polynomial algorithm of the regression graph. The formula was applied into DTM using Erdas Imagine 9.1 Spatial Modeller function.

Creating Slope and Terrace Lines

Creating slope map. Using the corrected DTM, plantation parameters such as slope, terrace lines and others were created and designed using 3D analyst tool of ArcGIS 9.2. Slope map was created...
using slope function of 3D analyst tool based on corrected DTM file. The slopes were classified into four categories as in Table 2.

Creating terrace line. Terracing is recommended for oil palm cultivation on land with a slope more than 7\(^\circ\). The standard specification of horizontal distance between terraces for oil palm cultivation is 9 m. The vertical distance between terraces is dependent on the degree of the slope and it is higher for the steeper slope compared to the gentler one. Figure 7 shows the schematic diagram of terraces in relation to degree of the slope.

For slope category 7\(^\circ\) – 15\(^\circ\), 11\(^\circ\) were considered as a mean of this slope category. The vertical distance (A) of the terraces in this slope category was determined by computing the 11\(^\circ\) in the formula which indicated the distance was 1.7 m. This value was then used to create the computerised terrace lines for the entire study area. For the slope category 16\(^\circ\) – 24\(^\circ\), 20\(^\circ\) was the mean and computation of the mean indicated that the vertical distance between the terraces was 3.4 m. The terrace lines and this value were derived by skipping one terrace line of the 7\(^\circ\)– 15\(^\circ\) slope category.

The corrected DTM was the basis of creating the contour lines. The terrace lines were created based on contour lines interval at 1.7 m as illustrated in Figure 7.

### Table 2. Four Categories of Slopes

<table>
<thead>
<tr>
<th>Slope</th>
<th>Categories</th>
<th>Terracing</th>
</tr>
</thead>
<tbody>
<tr>
<td>0(^\circ)– 6(^\circ)</td>
<td>Flat</td>
<td>No</td>
</tr>
<tr>
<td>7(^\circ) – 15(^\circ)</td>
<td>Rolling to undulating</td>
<td>Yes</td>
</tr>
<tr>
<td>16(^\circ) – 24(^\circ)</td>
<td>Hilly</td>
<td>Yes</td>
</tr>
<tr>
<td>&gt; 25(^\circ)</td>
<td>Steep</td>
<td>Yes</td>
</tr>
</tbody>
</table>

A & B is vertical distances between terraces

\[ A = \tan(11) \times 9 \]

\[ B = \tan(20) \times 9 \]
Main Road Alignment, Field Road and Drain

Road networks in oil palm plantation vary depending on the terrain, drainage, mill location and the distance to transport the FFB to the nearest road. It has to be well designed as it contributes to the FFB production and influence the costs of road installation, harvesting and transport (Corley, 2008). In this study, the main roads were considered as the block boundaries for the plantation. The roads were created in straight lines for every 20 planting lines on flat land. For hilly area, the road alignment cut across the terraces from the lower ground up to the hill top at 8° - 10° climbing slope. Sufficient drain networks are important for low lying areas to avoid flooding. General recommendation for drain intensity is one drain for every four to eight oil palm planting rows depending on elevation and water table levels of the area.

Flow Chart of the Study

All design works were based on 3D model for better visualisation. Figure 9 shows the flow chart of overall activities carried out in this study for
land evaluation and development for oil palm cultivation.

RESULTS AND DISCUSSION

Satellite Image Information

Enhanced SPOT-5 image of Figure 10, clearly shows the networks of logging tracts, cultivated areas, rivers, streams, settlement areas, land topography and land use of the study area. The logging tract networks indicate that the area had been logged and categorised as logged over forest. The topography of the area is hilly and the land surface slopes towards the Belaga River in the north-west side of the area. Many parts of the area had been cleared and cultivated by the natives who generally practised shifting cultivation. The image also indicates the existence of two settlements and a trunk road in the study area. Ground truthings verified the settlements as Ekran quarters and Long Koyan long house.

Land Area

The total area of land to develop at Sungai Asap, Belaga, Sarawak was 970.36 ha (Table 3). About 253.11 ha were considered as non-agricultural area because they were either at high elevation (>300 m) or contained high conservation value indicators (HCV) such as settlements, riparian zones and biodiversity conservation areas. After allocating about 4.98 ha of flat land at Parcel A1 for oil palm nursery, there were about 717.25 ha of the land potentially suitable to be cultivated with oil palm. Excluding the native land of about 110.69 ha, 606.56 ha of the potential suitable land were divided into three parcels (A, B and C). Parcels A and B were divided again into three blocks each and Parcel C into four blocks as shown in Figure 11.

Plantable Area

Out of the 717.25 ha of potential agriculture land, only 579.41 ha can be cultivated with oil palm. The rest of the areas were unsuitable because of too steep (> 25°) (Table 4). Further evaluation of the agriculture land indicated that 135.96 ha were hill locks and inaccessible (Table 5). After deducting the steep slope and hill locks areas, only 443.35 ha were suitable for oil palm cultivation.

Parcel A Analysis

The total area of Parcel A was 130.51 ha and plantable area was 82.85 ha, 63.48% of the total

Figure 10. SPOT-5 image of study area.
area. The remaining 47.66 ha (36.52%) were unsuitable for oil palm cultivation. These areas consisted of land with slope more than 25°, riparian zone, ravine and inaccessible area which were about 15.72, 6.36, and 25.59 ha respectively.

The estimated length of terraces for parcel A covering all the blocks were 41,466.64 m. The total stands count for all the blocks was estimated at 9989 palms, equivalent to average planting density of 121 palms per hectare. Table 6 shows the block analysis of Parcel A.

Parcel B Analysis

The total area of Parcel B was 198.63 ha and plantable area was 87.77 ha, 44.19% of the total area. The remaining 110.86 ha (55.81%) were unsuitable for oil palm cultivation because of too steep (>25°), buffer zone area and inaccessible hill lock area.

The estimated length of terraces for parcel B was 83,402.21 m. The total stand count for all the blocks in Parcel B was 11,612 palms, equivalent to average planting density of 132 palms per hectare. Table 7 shows the block analysis of Parcel B.

Parcel C Analysis

The total area of Parcel C was 277.42 ha and plantable area was 162.26 ha, 58.48% of the total area excluding the native land which was about 110.69 ha. The remaining 115.16 ha (41.51%) was unsuitable for oil palm cultivation because of too steep (> 25°), buffer zone and inaccessible hill lock area.

The estimated length of the terraces for Parcel C was 110,668.3 m. The total stand count for all the blocks was 20,659 palms, equivalent to average planting density of 127 palms per hectares. Table 8 shows the block analysis for Parcel C.
TABLE 4. SLOPE ANALYSIS OF STUDY AREA

<table>
<thead>
<tr>
<th>Land</th>
<th>Parcel A</th>
<th>Parcel B</th>
<th>Parcel C</th>
<th>Native land</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parcel area</td>
<td>130.51</td>
<td>198.63</td>
<td>277.42</td>
<td>110.69</td>
<td>717.25</td>
</tr>
<tr>
<td>Buffer zone</td>
<td>6.36</td>
<td>7.10</td>
<td>5.09</td>
<td>-</td>
<td>18.55</td>
</tr>
<tr>
<td>Slope class</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0° – 6°</td>
<td>61.80</td>
<td>47.59</td>
<td>77.59</td>
<td>101.69</td>
<td>288.67</td>
</tr>
<tr>
<td>7° – 15°</td>
<td>31.80</td>
<td>55.45</td>
<td>62.06</td>
<td>7.74</td>
<td>157.05</td>
</tr>
<tr>
<td>16° – 24°</td>
<td>14.82</td>
<td>40.12</td>
<td>77.69</td>
<td>1.04</td>
<td>133.67</td>
</tr>
<tr>
<td>&gt; 25°</td>
<td>15.72</td>
<td>48.48</td>
<td>54.97</td>
<td>0.22</td>
<td>119.28</td>
</tr>
</tbody>
</table>

TABLE 5. PLANTABLE AREA

<table>
<thead>
<tr>
<th>Land</th>
<th>Area (ha)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remaining area</td>
<td>717.25</td>
<td>100.00</td>
</tr>
<tr>
<td>Unplantable and reserve area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Slope &gt; 25°</td>
<td>119.39</td>
<td>16.65</td>
</tr>
<tr>
<td>• Inaccessible/hill lock</td>
<td>135.96</td>
<td>18.96</td>
</tr>
<tr>
<td>• Buffer zone</td>
<td>18.55</td>
<td>2.59</td>
</tr>
<tr>
<td>Total</td>
<td>273.9</td>
<td>38.2</td>
</tr>
<tr>
<td>Plantable area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Proposed area</td>
<td>332.88</td>
<td>46.4</td>
</tr>
<tr>
<td>• Native land</td>
<td>110.47</td>
<td>15.4</td>
</tr>
<tr>
<td>Total</td>
<td>443.35</td>
<td>61.8</td>
</tr>
</tbody>
</table>

TABLE 6. BLOCK ANALYSIS OF PARCEL A

<table>
<thead>
<tr>
<th>Land</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total area (ha)</td>
<td>57.14</td>
<td>34.11</td>
<td>39.26</td>
<td>130.51</td>
</tr>
<tr>
<td>Slope &gt; 25° (ha)</td>
<td>2.24</td>
<td>6.72</td>
<td>6.76</td>
<td>15.72</td>
</tr>
<tr>
<td>Buffer zone/drainage (ha)</td>
<td>1.60</td>
<td>2.03</td>
<td>2.73</td>
<td>6.36</td>
</tr>
<tr>
<td>Hill lock/inaccessible area (ha)</td>
<td>-</td>
<td>10.56</td>
<td>15.03</td>
<td>25.59</td>
</tr>
<tr>
<td>Nursery A and B (ha)</td>
<td>4.98</td>
<td>-</td>
<td>-</td>
<td>4.98*</td>
</tr>
<tr>
<td>Plantable area (ha)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Flat area (ha)</td>
<td>42.81</td>
<td>-</td>
<td>-</td>
<td>42.81</td>
</tr>
<tr>
<td>• Terrace area (ha)</td>
<td>10.50</td>
<td>14.8</td>
<td>14.74</td>
<td>40.04</td>
</tr>
<tr>
<td>Length of field road (m)</td>
<td>5 573.72</td>
<td>1 636.54</td>
<td>1 397.71</td>
<td>8 607.98</td>
</tr>
<tr>
<td>Density of field road (m ha⁻¹)</td>
<td>104.56</td>
<td>117.18</td>
<td>100.52</td>
<td>106.04</td>
</tr>
<tr>
<td>Length of terrace (m)</td>
<td>12 721.50</td>
<td>14 274.48</td>
<td>14 470.66</td>
<td>41 466.64</td>
</tr>
<tr>
<td>Density of terrace (m ha⁻¹)</td>
<td>1 211.51</td>
<td>1 022.09</td>
<td>1 040.67</td>
<td>1 080.66</td>
</tr>
<tr>
<td>Stand count (No.)</td>
<td>6 344</td>
<td>1 804</td>
<td>1 841</td>
<td>9 989</td>
</tr>
<tr>
<td>Planting density (palms ha⁻¹)</td>
<td>119</td>
<td>122</td>
<td>125</td>
<td>121</td>
</tr>
</tbody>
</table>

Note: *Area not counted in total area of Parcel A1.
CONCLUSION

Geospatial information technologies which comprise of GPS, RS and GIS have been proven useful for land evaluation for oil palm cultivation. The planters with knowledge and training on the softwares and materials used in the study can predetermine block boundaries, road and drainage alignment and area to be preserved. With the technologies, skills and knowledge on the use of GIS and remote sensing data, the planters could map and determine the road, drainage and terrace length and palm density. This information is useful for the planters in preparing the budget and contract for developing a new oil palm plantation. As the technologies undergo further development, and with the availability of more detailed data, planning and developing of plantation using information technologies will be made much easier and more precise. The GIS database thus developed can be used for future management and monitoring of the plantation activities. Under the present stringent requirement with respect to the environment, these technologies could assist the plantation in meeting the certification requirements. For further study, higher resolution of radar and multispectral
data can be incorporated to enhance the quality and accuracy of DTM. Interferometric synthetic aperture radar (IFSAR) with vertical interval of 1 m can provide actual earth elevation. It has been used to obtain DTM and digital surface model (DSM) for mapping and planning of oil palm plantation in MPOB Jerantut Research Station (Nordiana et al., 2012). However, after the land assessment, Parcel A was the only parcel developed for smallholder area. The remaining area was not developed due to the unsuitability of the area.

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