Financial Feasibility of UAV-based Forest Inventory of Teak Plantation: A Case Study of Khaokrayang Forest Plantation, Phitsanulok Province

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Abstract

Unmanned aerial vehicles (UAVs), commonly known as drones, are increasingly used in forest inventories and have the potential to increase labor productivity in teak forest plantations. However, the application of this new technology requires substantial investment in drone equipment and training operators. Therefore, the objective of this study was to analyze the cost to the relevant agency of using drones in forest inventory to provide forest stand volume and growth data. The costs of two methods of forest inventory were compared, namely the traditional, ground-based, forest inventory method and the drone-assisted method. The study was conducted in the Khaokrayang Forest Plantation of the Forest Industry Organization, located in Phitsanulok province, Thailand. A cost-benefit analysis was applied to compare the economic value over a 4-year period for each inventory method. Other uses of drones in other plantation management activities were assessed in addition to forest inventory, such as forest surveillance or tree survival surveys. The data were collected using UAV-based forest inventory and in-depth interviews on the cost of the traditional method and other forest management activities. The results showed that the costs of forest inventories could be lowered using drones. The case involving the of drones for forest inventory along with other plantation management activities, such as tree survival assessment and surveillance surveys, was most feasible with a net present value of THB 87,413, a benefit-to-cost ratio of 1.277, an internal rate of return of 51.36% and a payback period of one year and four months.

Keywords: 1) Cost - Benefit Analysis 2) Forest Economics 3) UAV 4) Forest Plantation 5) Growth

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Introduction

Unmanned aerial vehicles (UAVs), or drones, are increasingly used for natural resource management, such as monitoring, surveying, mapping and tracking. The advances in using drones enhanced with computer vision techniques, their practical advantages and their potential to reduce costs has resulted in their rapidly increasing use in natural resources and environment surveying, especially to access remote areas with difficult terrain. (Turner, Harley and Drummond, 2016)

Drones have provided efficient support for forest management activities, including forest stand mapping, tree volume surveying, forest inventory, monitoring and tracking illegal activities or wildfires and supporting research missions to restore forest areas (Puliti, et al., 2015). The application of drones in forest inventories has replaced traditional survey methods in plotting sample activities because the traditional methods require a certain amount of human labor to collect data and mapping information, which has high costs of both labor and time.

Using drones in forest inventory has advantages over ground surveys because the drones offer a high-resolution image which makes it possible to study the characteristics and classify the tree canopy, including the ability to operate at lower altitudes and achieve higher spatial resolution than conventional techniques (Zhang, et al., 2016). In addition, drones reduce the time needed for surveying, thus reducing the related capital and labor costs, and they can be deployed easily to facilitate updating inventories. This is especially applicable in hand-to-reach areas or remote areas, such as teak forest plantation in difficult terrain. Drone-derived images provide high resolution information at a lower survey cost than traditional techniques when carried out over a wide area or for long term forest surveying and monitoring. Images obtained by drones can be used to create precise, three-dimensional spatial models from which various variables of forest structure can be calculated, such as tree height, tree canopy and the density of trees.

Although the use of the drones for forest inventory purposes has many advantages, the adoption of new technology has limitations due to problems, such as calculating the canopy size to estimate the diameter of the tree requires a preprepared correlation equation. Furthermore, using a drone to conduct an accurate survey requires specific skills and sufficient technical knowledge for pilots that adds to training costs. Damage to drones during flight missions can be extensive and expensive. Potential users should be aware of such issues when considering using drones for forest inventory (Markiewicz and Nash, 2016).

In Thailand, in order to improve the accuracy and effectiveness of operational forest inventory, drones have been applied for forest management and inventory due to the advantages of technology, lower labor requirements, cost savings and easier access to difficult areas. The main aspects that distinguish the application of drones in forest inventory survey methods are related to cost effectiveness. Therefore, the objective of this study was to analyze the cost effectiveness of using drones for forest inventory compared to doing ground surveys and to study the economic efficiency of using drones to replacing manual labor in a forest inventory context. The results should provide information for decision makers to consider the use of drones in forest inventory and forest management to improve cost effectiveness and improve efficiency.

Literature Review

Research and studies have been widespread on the cost and cost-effectiveness of drone applications in various areas of exploration to manage natural resources. The use of drones is a time-saving and cost-effective way to track natural phenomena (Anderson and Gaston, 2013). It has helped users to reduce the limitations of many ground surveys, as using a drone would be less costly (Koh and Wich, 2012). Cutting-edge tools coupled with these technological advancements play an important role in tracking and exploring resources and ecosystems in the long-term (Paneque-Gálvez, et al., 2014; Whitehead and Hugenholtz, 2014).

Gardner, et al., (2008) studied the cost-effectiveness of an ecological diversity survey in the Brazilian Amazon in 14 different forest areas, using cost benefit analysis to compare each ecosystem survey method. That investigation differed from the approach of most researchers who focused on monitoring and assessing biodiversity for the benefit of site management and this may not take into account the best use of available resources. (Clothier, et al., 2015) studied public opinion on the adoption of drones in matters related to impacts and risks that may occur. They found that the attitudes of Australians were moderate to the use of drones and there was no feeling of insecurity or vulnerability or in any way being threatened. Thus, drones were considered to have a low impact on the general community life or people. (Haidari, et al., 2016) studied the economic value of the application of drones to transport vaccines, where there are limited means of transportation due to geographically different areas, populations and transit times, resulting in high transportation costs. The use of drones was considered cost-effective for the distribution of vaccines, especially compared to using a vehicle.

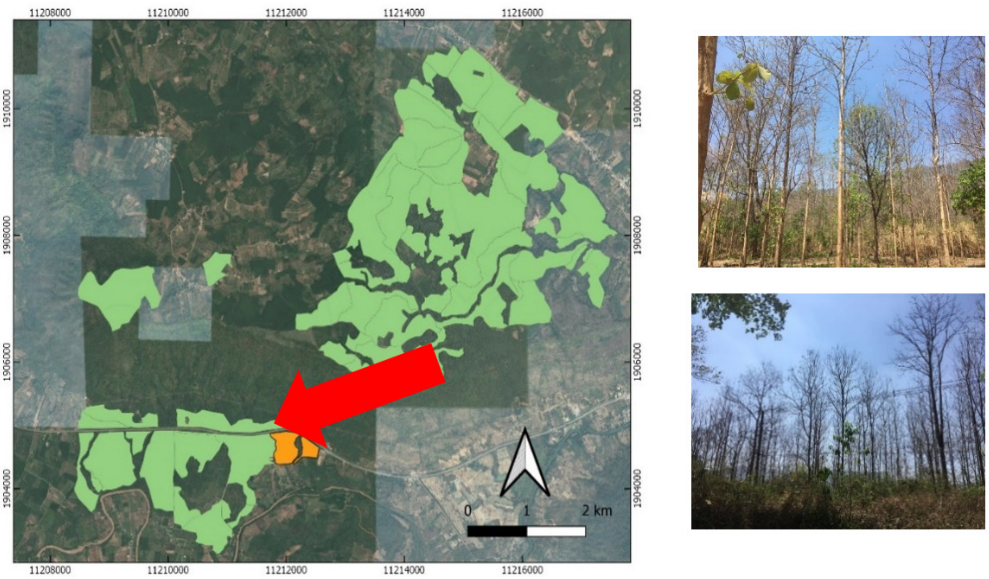
Markiewicz and Nash (2016) studied the use of drones to monitor forest areas in various parks and found that using drones was safer than using an aircraft that required a pilot to fly and it was less costly than using satellite imagery, could provide high-resolution imagery and was not affected by cloud cover. They also concluded drones did not affect or disturb wildlife as well as being easy to learn how to operate and use. However, there were some disadvantages of drones such as obtaining accurate positioning data requires adding a device with positioning capabilities which is expensive to install. The process of analyzing photographs obtained by drones takes a lot of time and sometimes complicates the procedure. Drones cannot be used during variable weather (wind and rain) while aircraft may be able to conduct surveys under such conditions. Drones can only be used in a limited flight area that is not too far from the remote-control device. The noise from a drone may negatively affect wildlife such as birds.

However, there have been limited studies regarding using drones in Thailand for forest inventory surveying and a program is required to interpret the results of photos to calculate the volume of wood. From past research, it was considered feasible to use drones in activities related to forest resource management or to explore the volume of wood. The current cost of drones is not very high and they are used in many countries. However, in Thailand, there are still some issues regarding the merits of its implementation as the survey of wood volume, especially for teak, is mostly limited to government plantations and or some private property where economic forest plantations are grown. Therefore, this study applied financial feasibility analysis to determine the cost-effectiveness and financial viability of using drones in teak forest inventory.

Methods

A conceptual framework for cost benefit analysis was developed based on the literature review. The study compared cost estimation using two methods of forest inventory surveying, namely traditional or ground surveys and drone surveys. The study collected comparative data on the two survey methods in similar teak forests in the Khaokrayang forest plantation, Phitsanlok province under the responsibility of the Forest Industry Organization. This teak forest plantation has a total area of 2,420 hectares, with a yield area of 1,616.6 hectares registered as a forest plantation under the Forest Park Act C.E. 1992 in Wang Thong district, amounting to 5,154 rai and in Nakhon Thai district (9,971 rai).

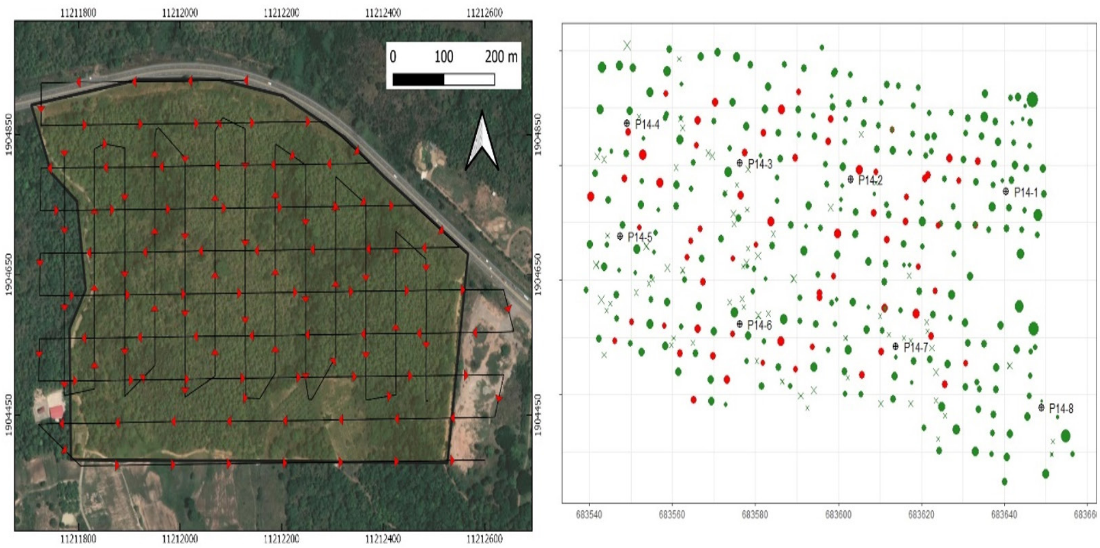
The study area was determined by staff of the Khaokrayang Forest Park and the researchers in a 1971 plantation (with supplementary planting in 2003) with an area of approximately 25 hectares (Picture No. 1). The Khaokrayang Forest Park maintenance and inventory plans provided data used in the study.



Picture No. 1 Study area in orange planted in 1971 (additional planting in 2003)

Data collection was conducted by interviewing Khaokrayng Forest Park staff on the actual costs of the two methods of forest inventory surveying. The researchers collected data and tested the use of drones in the study area during January–March 2020. A DJI Phantom 4 Pro unmanned aerial vehicle was used in the aerial surveys to estimate the wood volume. The survey flight line is shown in Figure 2 (left) and the manual survey results for tree diameter used for estimating the wood volume are shown in Picture No. 2 (right).

The study data were collected from reports and interviews in 3 parts: 1) 5 staff working in the Khaokrayang Forest Park during the period September 2019–February 2020 (consisting of the head of the Khaokrayang Forest Plantation, 2 of his assistants and 2 operational officers) were interviewed to obtain information on the general condition of the Khaokrayang forest plantation area, processes used and the activities and cost of surveying the teak volume of the Khaokrayang forest plantation; 2) 3 researchers under the project (consisting of the project leader, a co-researcher and a research assistant) obtained information on the drone equipment and costs of using it, including the nature of the use of drones in such research projects and the nature of the use of drones in activities related to the management of teak forest plantations; and 3) 1 expert in agricultural engineering with technical knowledge and experience in the construction and operation of drones provided information on the nature of activities in the teak plantation for which an unmanned aerial vehicle had the potential to replace manual workers. Lifetime estimation and drone life cycle estimation methods were applied to determine the number of accessories required in conjunction with the drone.



Picture No. 2 Drone flight plan (left) and results of manual survey of diameters (right)

The data were analyzed based on: net present value (NPV), benefit cost ratio (BCR), internal rate of return (IRR), payback period (PB) of the project with 4 years of project life according to the age of the drone equipment and a discount rate 6.875% (from the average reforestation loan interest rate of the Bank for Agriculture and Agricultural Cooperative in 2019). It was assumed the forest inventory survey activities were conducted annually in all areas of the Khaokrayang Forest Park during 2021–2024.

Results and Discussion

The investigated the cost-effectiveness of using drones for teak forest inventory data collected in the Khaokrayang forest plantation of the Forest Industry Organization. The costs were collected for 2 main activities: 1) the cost of forest inventory surveys based on traditional methods using circular plot sampling; and 2) the cost of forest inventory survey using a drone. The drone photography was captured based on a Double Grid Mission flight at an altitude of 140 meters from the ground.

Each method of measurement had different costs. The forest inventory survey based on the plots had a major investment in fixed costs, such as instrument to measure the circumference of each tree, length measurement tape, instrument to measure the height of each tree. Other equipment used in the survey consisted of a global positioning system (GPS) and a vehicle to travel to the survey area. The variable costs included the labor cost to carry out the survey, wages for the interpretation program, fuel and equipment, such as machetes, as shown in Table No. 1. Using drones, the main investment in fixed cost was for the drone and aviation-related equipment including battery charging equipment, amplifier, spare propeller, memory card, smartphone, wood volume calculation software and instruction for staff regarding drone flight training and using the interpretation program. The variable costs consisted of operating costs, such as electricity and flight operator wages.

There is a large cost or investment required in using drones or technology to help determine the wood volume. However, the results from the present study found that using a drone could save time in surveying while also obtaining accurate images and information. The drone could access and be used in almost any terrain, even on steep slopes, hills and cliffs, where manual access is difficult. However, this required a drone operator with experience and expertise in specific areas. The results obtained from the drone survey had low tolerances for processing or measurement regarding forest inventory. These were advantageous points regarding using drones to help in forest inventory.

Although the manual method of forest inventory involving locating sample plots had a high cost of labor for on-ground work, this method had advantages that technology cannot compete with, such as being able to check the quality of the tree and measure the diameter and height of the tree based on actual trees in the representative sample and getting information on the condition of the trunk. Furthermore, local workers can be employed and community relations developed, with additional monitoring benefits from accessing the plots on the ground, such as pruning or trimming tree in one-time survey and inspection of firebreaks.

Table No. 1 Cost data comparison for 2 forest surveying methods

Traditional method (sample plots)	Using drones (UAV)
1. Fixed cost • GPS equipment model Garmin Oregon 500 • measuring device, measuring tape, wood tape 1:10 • facilitating device; machetes • inspection vehicle • printer • portable computer 2. Variable cost • equipment maintenance costs • labor wages for survey • data processing costs; forest staff or specialists • other expenses; fuel, office materials	1. Fixed cost • Drone, battery, charging device, signal amplifier, spare propeller, memory card • smartphone control, control of flight plan. • wood volume surveying software, specific area program • training cost in flight and using interpretation program 2. Variable cost • equipment maintenance costs • electricity for charging battery • UAV pilot wages • other expenses; fuel, office materials
Advantages	**Advantages**
1. Wood volume can be measured based on actual trunk measurements of representative trees, information on tree condition can be collected. 2. Low investment cost. 3. Employment of local workers and community relations benefits. 4. Additional benefits during ground access to plots, pruning or trimming tree and inspection of firebreaks.	1. Save time in accessing trees. 2. Obtain accurate image and information because to provide total number of trees. 3. Can be used in almost any terrain, access even to steep slopes, hills and cliffs that are difficult for human on-ground access. 4. Low tolerances in measurement.

In 2019–2020, the fixed and variable costs associated with surveying to estimate the increase in volume of the teak plantation using sample plots are detailed in Table No. 2. The main fixed costs were: global positioning system, inspection vehicle and the computer. The costs were calculated in proportion to their usage in the forest inventory survey activities of the Khaokrayang forest plantation. The cost of the vehicle accounted for 15% uses each year. In addition, most of the variable costs arose from the labor wages associated with the ground survey of THB 123,766 and the average variable cost each year was approximately THB 82,200–84,400. The total cost during the 4-year project life was THB 453,046.

The cost of carrying out the forest inventory using a drone in this study was divided into 2 cases: 1) only using a drone in the forest inventory survey, where 1 drone was used; and 2) using drones for overall management in the forest plantation area including forest inventory, where the drone could be used for various forest management tasks, such as aerial surveys, surveying the survival rate of teak trees, forest fire surveillance, surveillance of illegal activities, which did not require much additional cost. So, in the second case, using drones to perform other activities was more flexible and supported improved management of the forest plantation.

Table No. 2 Cost details of timber volume survey based on ground plots

Cost	Detail	Usage (%)	Price per unit (THB)	Year (THB)				
				0	1	2	3	4
Fixed cost								
GPS	1 unit	100%	27,000	27,000				
Distance measuring tape	1 piece	100%	320	320				
Measuring tape	1 piece	100%	50	50				
Table	1 piece	100%	35	35				
Printer	1 unit	15%	3,790	569				
Computer	1 unit	15%	23,000	3,450				
Survey truck	1 unit	15%	614,018	92,103				
Variable cost								
Machetes	1 piece	100%	240	240		240		240
Labor	5 persons/ 6 hr day	30 days	400		60,000	60,000	60,000	60,000
Skill outsourcing	1 person	100%	20,000		3,000	3,000	3,000	3,000
Fuel	30 days	100%	500		15,000	15,000	15,000	15,000
Office supply	1 unit	100%	1,500		1,500	1,500	1,500	1,500
Maintenance	Yearly	15%	18,000		2,700	2,700	2,700	2,700
Cost per year				123,766	82,200	82,440	82,200	82,440
Toral cost (THB)	453,046							

For case 1, using a drone only for forest inventory survey, the investment costs were for 1 drone and all the necessary equipment used in flight planning. In addition, an interpretation program was required to calculate the volume of teak trees from the images. This study used the timber volume survey program developed under the Precision Forestry Applications Project in teak plantations in northern Thailand. There was a development cost of THB 400,000 for a teak forest plantation in the landscape of the lower northern region, including Phitsanulok, Uttaradit and Tak, based on 18 teak plantations. Thus, this study used the average cost of the program. However, accurately calculating the volume of teak requires a specific set of additional programs developed to suit the terrain, including the average diameter canopy size and the height of the teak trees. In order to interpret the results, there was an additional cost of about THB 30,000, as shown in Table No. 3. In addition, there were fixed costs of THB 222,802 and variable costs each year were THB 33,167–40,367 over the project period of 4 years, with a total cost of THB 369,870.

Table No. 3 Case 1: Cost of using a drone for forest inventory survey

Cost	Detail	Usage (%)	Price per unit (THB)	Year (THB)				
				0	1	2	3	4
Fixed cost								
UAV	1 unit	100%	56,200	56,200				
Electricity charging device	1 unit	100%	3,800	3,800				
Device signal amplifier	1 unit	100%	300	300				
Spare propeller	2 unit	100%	200	400				
Memory card	2 unit	100%	1,250	2,500				
Smartphone	1 unit	100%	15,000	15,000				
Wood volume survey software	1 unit	7%	400,000	28,000				
Additional programs	1 unit	100%	30,000	30,000				
Training fee	2 person	100%	9,000	18,000				
Survey truck	1 unit	10%	614,018	61,402				

Cost	Detail	Usage (%)	Price per unit (THB)	Year (THB)				
				0	1	2	3	4
Variable cost								
Additional battery	3 pieces	100%	7,200	7,200		7,200		7,200
Battery charging fee	Per year	100%	3,517		3,517	3,517	3,517	3,517
Insurance	Per year	100%	10,500		10,500	10,500	10,500	10,500
Computer	1 unit	15%	23,000		3,450	3,450	3,450	3,450
Fuel	5 days	100%	500		2,500	2,500	2,500	2,500
Flight staff	2 person/day for 5 days	100%	1,000		10,000	10,000	10,000	10,000
Office supply	1 unit	100%	500		500	500	500	500
Maintenance	Per year	15%	18,000		2,700	2,700	2,700	2,700
Cost per year				222,802	33,167	40,367	33,167	40,367
Total cost (THB)	369,870							

For case 2, using drones for overall management in the forest plantation area including forest inventory along with aerial surveys, survival rate of trees, and forest fire surveillance and surveillance of illegal activities that require human labor or involve degree of difficulty and risk. In case 2, the cost of investment or fixed cost was calculated proportionally, with 3 drones required to cover the greater number of activities. During the same 4-year project period, the 3 drones were used simultaneously to do the activities, with survey for forest inventory accounting for 25% of all drone activity. In addition, when using the drone for forest inventory, the number of days spent exploring was reduced from 30 days to 5 days, with reductions also in a decrease in the proportion of time required for inspection vehicles, as shown in Table No. 4.

Table No. 4 Case 2: Cost of using drones for overall management in forest plantation area including forest inventory

Cost	Detail	Usage (%)	Price per unit (THB)	Year (THB)				
				0	1	2	3	4
Fixed cost								
UAV	3 unit	25%	168,600	42,150				
Electricity charging device	3 unit	25%	3,800	2,850				
Device signal amplifier	1 unit	25%	300	75				
Spare propeller	4 unit	25%	400	400				
Memory card	2 unit	25%	1,250	625				
Smartphone	1 unit	25%	15,000	3,750				
Wood volume survey software	1 unit	7%	400,000	28,000				
Additional programs	1 unit	100%	30,000	30,000				
Training fee	2 persons	100%	9,000	18,000				
Survey truck	1 unit	10%	614,018	61,402				
Variable cost								
Additional battery	9 pieces	25%	7,200	16,200		16,200		16,200
Battery charging fee	Per year	100%	3,517		3,517	3,517	3,517	3,517
Insurance	Per year	25%	10,500		2,625	2,625	2,625	2,625
Computer	1 unit	15%	23,000		3,450	3,450	3,450	3,450
Fuel	5 days	100%	2,500		2,500	2,500	2,500	2,500

Cost	Detail	Usage (%)	Price per unit (THB)	Year (THB)				
				0	1	2	3	4
Flight staff	2 person/ day for 5 days	100%	1,000		10,000	10,000	10,000	10,000
Office supply	1 unit	100%	500		500	500	500	500
Maintenance	Per year	15%	18,000		2,700	2,700	2,700	2,700
Cost per year				203,452	25,292	41,492	25,292	41,492
Total cost (THB)	337,020							

The objective of the forest inventory survey was to obtain a volume estimate of the amount of teak wood in the different plots in order to gain information for planning and decision making. The application of drones in forest inventory surveying is a potential method to replace traditional, manual, ground-based methods. The comparative appraisal was based on cost-benefit analysis for both methods.

The results of the study on the financial feasibility of using drones for forest inventory surveying indicated that in case 1 using a drone only for forest inventory survey was a feasible for investment, as shown in Table No. 5, with an NPV over the 4 years of project period of THB 56,091 THB (greater than 0), with a BCR of 1.162 (greater than 1) and an IRR of 30.38% (greater than the discount rale or the project interest rate), with a payback period of 2 years and 9 months, indicating that using drones for forest inventory was a worthwhile investment.

Table No. 5 Financial value, case 1: using a drone only in forest inventory survey

Year of operation	Cost (THB)	Benefit (THB)	Net benefit (THB)	Net present value of costs (THB)	Net present benefit (THB)	Annual net present value
0	222,802	123,766	(99,036)	222,802	123,766	(99,036)
1	33,167	82,200	49,033	31,033	76,912	45,879
2	40,367	82,440	42,073	35,341	72,175	36,834
3	33,167	82,200	49,033	27,169	67,335	40,166
4	40,367	82,440	42,073	30,940	63,188	32,248
Total				347,285	403,377	56,091

Year of operation	Cost (THB)	Benefit (THB)	Net benefit (THB)	Net present value of costs (THB)	Net present benefit (THB)	Annual net present value
Net present value						**56,091**
Benefit cost ratio						**1.162**
Internal rate of return						**30.38%**
Payback period						**2 yr 9 mo**

In case 2, using drones for overall management in the forest plantation area, including forest inventory, as shown in Table 6 was a good investment with an NPV of 51.36% and a payback period of one year and 4 months. The results of the study indicated that in this case although there was greater investment required in the use of more drones, there was a higher return than for the first case in both the NPV and IRR, with a shorter payback period.

Table No. 6 Financial value, case 2: using drones for overall management in forest plantation area, including forest inventory

Year of operation	Cost (THB)	Benefit (THB)	Net benefit (THB)	Net present value of costs (THB)	Net present benefit (THB)	Annual net present value
0	203,452	123,766	(79,686)	203,452	123,766	(79,686)
1	25,292	82,200	56,908	23,665	76,912	53,247
2	41,492	82,440	40,948	36,326	72,175	35,849
3	25,292	82,200	56,908	20,718	67,335	46,617
4	41,492	82,440	40,948	31,802	63,188	31,385
Total				315,963	403,377	87,413
Net present value						**87,413**
Benefit cost ratio						**1.277**
Internal rate of return						**51.36%**
Payback period						**1 yr 4 mo**

Conclusion

The use of technology to replace human workers supports increasing productivity as well as saving operational costs. The application of drones in teak forest inventory (to replace the traditional ground-based manual labor method) and in general forest management was used as a case study in the Khokrayang Forest Plantation of the Forest Industry Organization in Phitsanulok province. There is no published record of drones being in forest inventory survey in the forest plantations of the Forest Industry Organization. The application also required the development of a program to analyze the survey results simultaneously. This was a new initiative requiring early investment so the current study was undertaken to provide information regarding the cost-benefit analysis of using drones.

The results of the study showed that the adoption of drones was cost effective. It produced cost savings compared to traditional surveys, because less labor was needed using drones in conjunction with other forest plantation management activities, such as aerial surveys, tree survival rate surveys, wildfire surveillance and surveillance of illegal activities, which are regular activities of forest park officials. In this case, the use of drones for inventory surveying in conjunction with other activities was more cost effective than investing in drones for forest inventory activities alone. Thus, large teak plantation should also consider investing in drones for plantation management.

In addition to drones introducing new technology to forest inventory surveying to reduce costs, they can also save time during surveying compared to the traditional, ground base, manual tree measurement methods. In addition, drones can explore in detail trees located in areas where ground-based access is difficult. However, based on the results of the study, there are still some limitations in using drones to estimate wood volume in standing tree, such as the operator of the UAV must be skilled in flying, a processing program is required and there may accidents and damage due to the UAV flying into obstacles while being remotely operated. Some detailed inspection requires flying at allow altitude to obtain sufficient detail, increasing the risk of collisions involving the UAV. The on-ground presence of workers does provide additional benefits, such as cutting branches, opening up access tracks and maintaining firebreaks at the same time as accessing the ground plots. Furthermore, the reduction in the traditional labor force may adversely impact income in local communities.

Recommendations from the results of this study are: 1) The application of drone technology in forest inventory surveys is financially feasible and a suitable investment; 2) the use of drones should be applied in parallel with other forest plantation management activities (tree survival rate surveys, aerial surveys, prevention of illegal logging among others) to provide the highest return and a shorter period for payback; and 3) drones can be used to replace workers in forest surveying to some extent, although some staff are still required for many forest management activities. Therefore, choosing to invest in drones should be coupled with other forest plantation management activities, with drones being used to gain time and cost reductions but only by a carefully determined reduction of existing labor.

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