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Mobile app for eucalyptus bucking - value chain optimization for smallholders

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Research Article

Keywords: Tree bucking optimization, taper curve, dynamic programming, EVO application

Posted Date: March 31st, 2023

DOI: https://doi.org/10.21203/rs.3.rs-2673227/v1

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Version of Record: A version of this preprint was published at Small-scale Forestry on March 7th, 2024. See the published version at https://doi.org/10.1007/s11842-024-09563-5.

Abstract

Eucalyptus plantations are a notable source of income for smallholders and private landowners in Thailand. The main uses of eucalyptus are for energy purposes and as pulpwood, sawn timber, and veneer. Among private eucalyptus forest owners there is a need for decision support tools that can help in optimizing tree bucking, according to the available properties of the site and bucking patterns. The precise characterization of plantation properties is key to delivering appropriate timber assortment to markets and optimizing timber value. Our study has developed and tested dynamic programming models for optimizing the tree bucking of eucalyptus trees. To achieve this, tree taper curves for use in volumetric models were defined for optimization. Our results indicate that both the tree spacing and the increment of diameter of breast height are significant factors when estimating profitability. The income would be significantly higher if bucking timber in different assortments were used, instead of the current approach of selling as bulk based on mass. For implementation, we created a free mobile application for android phones (EVO—eucalyptus value chain optimization) to utilize the study results at the grass root-level.

1 Introduction

Eucalyptus plantations are a notable source of income for smallholders and private landowners in Thailand. Cultivated areas of eucalyptus trees are grown in different sizes of block patterns, in small-scale areas along canals, or beside paddy fields and scattered around settlements. Commonly, eucalyptus breeding is one source of income among other land uses for farmers. Eucalyptus plantations provide wood for smallholders' own use, as well as providing income from the selling of timber. Eucalyptus is a versatile species that can be used for energy purposes, and as pulpwood and sawn timber for furniture or construction. According to FAO statistics (2001), the estimated area of eucalyptus plantations was approximately 480,000 ha in Thailand at the beginning of the millennium, but the cultivation area has drastically increased to about 1.8 million hectares in recent estimations (Haruthaihanasan 2016). This is a consequence of the current annual planting area of eucalyptus being about 40,000 ha (Luangviriyasaeng 2003). The main advantage of eucalyptus cultivation compared to other commercial tree species for smallholders is its short rotation time, which means logging revenue can be derived frequently and regularly. At the general level of Thailand's forest policy, the Royal Forest Department is promoting the growth of economically utile tree species, including eucalyptus, to boost the grass root-level economy by supporting over 4 million ha new plantations via the subsidizing of farmers, which will increase eucalyptus' logging potential in future (Faculty of Forestry 2017). The general situation is that Thai timber markets do not fully recognize the value of different eucalyptus timber assortments. In an ideal situation, eucalyptus logs would be graded based on diameter sizes, and forestry companies would determine the purchase prices on the market. Forestry companies perform log sorting in their mill yards if this supports their refinery process. However, this may not be the most beneficial approach for smallholders, who sell their timber at bulk price (THB/ton). Firstly, the main is that supply and demand need to be created in Thai markets. Due to both governmental subsidies and general interest in eucalyptus, numerous new smallholders are frequently emerging who want to sell their first eucalyptus yield. These new smallholders would benefit greatly from a simplified, easy-to-use decision-making tool for evaluating the economic impacts of eucalyptus forest management options. At present, mobile device-based applications are becoming part of forestry work as a tool to monitor and inventory forest stands (TRESTIMA), and as a decision-making tool for use in relation to stem-level bucking (T4E Bucking), to mention some of the main uses (Vastaranta et al. 2015; Erber et al. 2021).

The forest industry has adopted operational research tools and developed terms for enhancing wood supply chains. According to Cooper et al. (1997), supply chain management (SCM) relates to planning, implementing, and controlling both material and information flows in the most efficient ways. One important part of SCM concerns how to optimize raw material allocation. In the area of forest engineering, one of the traditional raw material allocation problems is related to tree bucking. The problem can be presented in the form of the question: “What is the best possible way to cut tree stems into logs?” Laroze (1999) further unpacked this tree bucking problem at three levels: the stem, stand and forest levels. Generally, private forest owners are most interested in stem- and stand-level tree bucking, and the forestry industry generally focuses on forest-level bucking. Fortunately, the tree bucking problem can be effectively tackled using advanced computer systems. As forestry has developed with the use of computer-aided support systems, tree bucking optimization has come to be handled using mathematical models (Näsberg, 1985). Dynamic programming (DP) has been found to be useful in optimizing the value of individual trees (Pnevmaticos and Mann, 1972; Faaland and Briggs 1984). Recently, as new tree bucking optimization models have been developed, DP modeling remains one of the most useful tools (Akay et al 2010; Arce et al., 2002). To solve the bucking problem, several types of software have been developed over the decades to address chainsaw bucking: BUCK was developed for use on handheld computers to optimize stem-level bucking at the stump (Sessions et al. 1988); TREEVAL was developed to both optimize bucking patterns and compare user-specific bucking patterns (Briggs 1989); the AVIS program was developed to optimize crosscutting via DP on microcomputers and mobile devices (Geerts and Twaddle, 1984). When evaluating the chainsaw operator's recovered log volume and value, several studies have made great strides towards bucking pattern optimization (Garland et al. 1989; Olsen et al. 1997; Bowers et al. 1998; Wang et al. 2004, 2009; Akay et al 2010).

Erber et al. (2021) found that, when the optimization of the bucking pattern using an app was unsuccessful, the reason was often a deviation between the estimated and observed stem taper curves. Tree taper curves are essential to the optimization of tree bucking. Modern tree bucking is based on tree taper models, which enable estimations of the volume and mass of the stem. Heinonen et al. (1996) formed polynomial taper curve functions for *Eucalyptus grandis* and *Eucalyptus cloeziana* in Zambia. They discovered that in estimating tree volume, only the diameter at breast height (DBH) and height were necessary for incorporation into the taper curve when tree was small. Eerikäinen et al. (1999) compared different methods, and found the polynomial taper curve to be reliable for predicting the stem volume of *Eucalyptus cloeziana* in Zambia and Zimbabwe, even though some inaccuracies regarding stem form could not be avoided, such as those related to population dynamics, provenance factors, and geographical site variation. Mabvurira and Eerikäinen (2002) developed a taper curve approach for *Eucalyptus grandis* in Zimbabwe. They discovered that the basic logarithmic form could provide good estimates of volume when DBH and height were used as the predictor variables. Thai eucalyptus forestry is based on clones developed by forestry companies for different kinds of growth conditions (Sirijaroonwong et al. 2017 Sawiangphon et al. 2021). The detailed information about the original subspecies of eucalyptus have been classified as business secrets to protect the research and development work of companies.

In light of the above-mentioned studies, a decision support tool for eucalyptus smallholders must be developed based on the following principles. i) Local characterizing properties need to be taken as input values, i.e., the prices of different assortments and bucking parameters. ii) In the accurate estimation of stem volumes, the calculation must be based on the local taper curve because Thai eucalyptus plantations are established based on local clones, not general subspecies. iii) The decision support tool must be built in a comprehensive manner, such that users simply add basic parameters (e.g., tree diameter, height and taper; stand volume) to a clear platform, i.e., a mobile device application.

The aim of the study was to form and test dynamic programming models for optimizing tree bucking and maximizing the yield/economic performance of eucalyptus forest management approaches at selected time points. To do this, we have created a taper model and collected data relating to supply chain factors and market prices, as well as verifying our models and creating a mobile application to download for free. With these decision support tools, eucalyptus growers can maximize their production efficiency and optimize end-product performance.

2 Materials And Methods

This study is divided into four different sections: tree taper modeling, verification of the modeling results, dynamic modeling of tree bucking, and determining the test parameters for the scenario analysis of the mobile app. The modeling, verification and scenario analysis data were collected from the Kanchanaburi, Ratchaburi, and Suphanburi provinces in the western Thailand.

2.1 Eucalyptus tree taper modeling

The tree taper data were collected from privately owned eucalyptus plantations. The average DBH of eucalyptus generally varied between 2 and 4 inches in the study area. The majority of forest-owning farmers were smallholders; they did not seek to add value by letting their trees grow larger. Here, once a tree had matured to market size, the farmers harvested it. Market size is usually reached when trees are 4–5 years old, with an average DBH of approximately 3–5 inches. The total height of the tree is relatively dependent on tree size; if the tree is taller, a greater log yield may be available for bucking, and more timber assortments can be attained. That said, in order to obtain bigger trees, the rotation time must be longer. Only a few farmers, who were sufficiently wealthy and had large plantations, waited until their trees were bigger and sold them for higher prices in product assortments.

Tapers were mathematically developed using regression modeling. Based on the current situation of the Thai eucalyptus market, the tree taper curves were modeled using five DBH classes: <2 inches; 2–3.99 inches; 4–5.99 inches; 6–7.99 inches and > 8 inches. Normal trees growing on the plantation were selected as sample trees. Data on the diameters of stems were collected using calipers from 90 recently felled trees (Table 1). The diameters were measured at 100 cm intervals along the stems, and the starting point was the DBH, measured 1.3 meters above the ground level. The diameter was measured at a marked location to an accuracy of 1 mm on either side of the tree. Diameter measurements were taken until the top was reached. The collected data concerned trees from different clones, and with different spacings, ages, and rotation phases, so as to ensure an adequate amount of trees were sampled to develop taper models for the different diameter classes. Secondly, the taper curves were intended to be incorporated into the decision-supporting tool, wherein general coverage was the most desirable character.

Table 1
Example trees' taper curve data (n = 90).

DBH classes, inches	Age, years	Average DBH, cm	Average height, m	Number of sample trees, n
< 2.00	4	3.9	7.9	22
2.00-3.99	4	6.9	12.14	27
4.00-5.99	4	13	16.1	13
6.00-7.99	10	17.5	18.26	21
> 8.00	> 10	26.5	20.92	7

2.2. Calculations for verification of the taper curve

After the taper curve equation had been developed, it was necessary to undertake a verification process to ensure its accuracy. Sample stems from each diameter class were harvested for the validation of the taper model during the second field visit (Table 2). The logs were bucked to log lengths most favored at local markets by a chainsaw operator. Measurements of the diameter at each log's midpoint, large end and small end were carried out in order to estimate the volume.

Table 2
Example tree descriptions for taper curve data verification (n = 47).

DBH classes, inches	Average DBH, cm	Average height, m	Number of sample trees, n
< 2.00	4.1	6.11	9
2.00-3.99	7.4	10.33	16
4.00-5.99	10.9	13.71	8
6.00-7.99	16.8	18.34	11
> 8.00	23.4	23.78	3

The volumetric model was calculated using Newton's formula [1]. A model for the total volume of the stem was created based on the individual log volumes.

$V_{Log} = (B + 4B_{1/2}$ +b) / 6*L [1]

where

V_{Log} is log volume, m^3;

$B_{1/2}$ is the cross-sectional area at the log's midpoint, m^2;

B is the cross-sectional area at the large end of the log, m^2;

b is the cross-sectional area at the small end of the log, m^2;

L is the log length, m.

The fresh weights of each log were measured with a weight scale, and ultimately all log records were combined to derive the total stem weight. Stem-wise correlations between log volume and weight were undertaken. The fresh density of the eucalyptus stems was calculated immediately after felling based on the fresh weight and calculated volume. The fresh density of stems was determined as 1016 kg per ton. This metric was used to convert log volumes to tons, because the Thai forestry market operates via the weights of eucalyptus logs.

2.3. Dynamic programming for calculating the best tree bucking

The log lengths, the diameters of the timber assortment classes, and the timber prices used are based on the actual situation, as derived during the data collection in western Thailand (Table 3). The four classes used relate to the minimum diameter limits of woodchip logs, pulpwood logs, saw logs, and veneer logs, respectively. Additionally, this classification is hierarchical; timber assortments from the higher class meeting the conditions of the minimum-diameter class can be transferred to a lower class, but not to a higher one. For example, the saw log assortment can be used as pulp wood, but saw log wood meeting the minimum diameter conditions cannot be used as veneer log.

Table 3
The default values of timber assortments for dynamic programming. The prices of assortments are average based on the information from mills in the study area.

Assortment	Scaling length, m	Scaling diameter, inch	Price, THB/ton
Veneer	1.3	> 8	2000
Sawn timber	3	> 6	1600
Pulp log	2	> 1.5	1200
Woodchips	unlimited	unlimited	600

The process of cutting a tree stem into logs with the highest aggregate value is commonly referred to as bucking to value (Sondell 1987). The stem-level bucking optimization approach is based on dynamic programming (DP). Dynamic programming employs a target function, which is divided into sub-parts that are optimized according to the set limitations. The goal of tree-level bucking optimization is to assign each stem a bucking pattern that yields the highest total stem value. This process requires two components: 1) the stem profile and 2) all the possible length−diameter combinations of logs, the values of which reflect profitability on the market. A tree stem is divided into N segments, the optimal bucking pattern of which is determined by recording the highest cumulative log value at each stage and the starting position of the last log (Näsberg 1985). The algorithm is then applied in this manner all the way up to the top of the stem. The stem diameter and volume are calculated using taper models as a function of the breast-height diameters and heights of the trees. Dynamic programming generates several alternative cutting options for each stem. After calculating the monetary value of each option via the price, the option yielding the highest value is selected (Fig. 1). The stem data utilized for DP are presented in Tables 1 and 2.

2.4. EVO bucking application for mobile phone and its scenario analysis testing

The stem function and bucking optimization processes can be considered universal points of interest, due to the global and widely known nature of the problems involved, whereas harvesting and transportation cost calculations are regional issues. Hence, we developed an application tool that takes the local operation costs into account when performing profitability calculations that yield real incomes to be derived from the selling of timber assortments. The mobile bucking application EVO (eucalyptus value chain optimization) was first created on Microsoft Excel, and was based on the above-mentioned tree taper and dynamic programming models used for testing bucking optimization and to maximize production efficiency based on the market situation (Fig. 2). The necessary background information here includes the market prices of timber assortments; these are pre-defined values, but the user can change them depending on the current local situation. Additionally, the EVO also includes information on the location of refining factories in western Thailand. General harvesting (THB/ton) and transportation (THB/ton km) costs have been defined and established as additional default values. This background information was collected during two field survey trips.

In order to establish the applicability of the models presented above, we have performed tests assessing whether the EVO app gives consistent results in different scenarios. The scenario analysis included four different test cases. The first test set (CASE 1) comprised a basic situation on a eucalyptus plantation of one hectare, where the average DBH was three inches and the spacing of trees was on a 2x3 m pattern. In order to demonstrate the effects of growth on the projected incomes and costs, we also established CASE 2, where the average DBH was increased from three to six inches, while the other conditions remained the same (ceteris paribus of assumptions for all cases). The third case (CASE 3) was used to demonstrate the effect of an even greater DBH on the costs and incomes. The fourth case study (CASE 4) was used to illustrate the effects of spacing on the costs, profits and incomes. Additionally, in all case studies, the harvesting cost (200 THB/ton), the transportation distance (from forest to mill; 50 km) and cost (10 bath/ton/km), and the unit prices of assortments (Table 3) were fixed, and the calculation was performed with a 100% survival rate and homogeneous growth for all trees. The input data used for the calculations are presented in Table 4.

Table 4
Site descriptions for each case (1–4) of the scenario analysis.

	Site descriptives		
Test case	Harvesting area, ha	Spacing, m	Average DBH, inch
CASE 1	1	2 x 3	3
CASE 2	1	2 x 3	5
CASE 3	1	3 x 3	5
CASE 4	1	3 x 3	7

3 Results

3.1. Stem functions—regression equations and taper curves

Every diameter class has specific parameters relevant to the taper model equation. The volume is taken as the response variable and DBH is the interpret factor; the third-order regression model gave the best response (Eq. 2). As the lengths of eucalyptus trees in plantations are commonly known to correlate fairly strongly with their DBH, other attributes did not necessarily have to be considered when the verification data were used to improve the coefficient of determination (Table 5).

$$Y = \mathrm{a}\mathrm{X}^3 + b\mathrm{X}^2 + c\mathrm{X} + \mathrm{d} \ [2]$$

where

Y is the stem volume, m^3;

X is the diameter at breast height, m;

a, b, and c are the model parameters;

d is the error term.

Table 5
The coefficients and R2s of the taper modeling process undertaken with third-order regression equations for each of the DBH classes. Initial equations based on data of 90 trees and adjusted equations, including the verification data of 47 trees.

	Initial taper equation					**Adjusted taper equation**				
DBH class	a	b	c	d	R2	a	b	c	d	R2
< 2.00	-0.0006	0.083	0.1854	1.7259	0.611	-0.0118	0.1401	0.6747	2.336	0.775
2.00-3.99	-0.0005	0.0075	0.212	2.9918	0.713	-0.0027	0.0566	0.5523	3.7447	0.601
4.00-5.99	-0.0007	0.0202	0.4572	5.6684	0.752	-0.0037	0.0807	0.7787	5.466	0.943
6.00-7.99	-0.0007	0.0247	0.6379	8.5457	0.667	-0.0006	0.0224	0.5695	7.4851	0.927
> 8.00	-0.0007	0.0293	0.8186	11.423	0.583	-0.0005	0.0027	0.4642	9.9385	0.843

The initial taper equations displayed a low coefficient of determination for all diameter classes. After the second field trip, more tree stem samples were added to adjust the taper equation. The adjusted taper equations then yielded higher R^2 values, which were taken as adequate for this study, especially in terms of the DBH classes most commonly used when making harvesting decisions. The taper curves of every DBH class are presented visually in Fig. 3.

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Figure 3. Tree taper curves for each diameter classes.

3.2. Bucking based on tree taper equation result

Table 6 shows examples of bucking patterns for each DBH class. The DBH sizes were chosen as the middle points of the classes: 1, 3, 5, 7, and 9 inches. The bucking optimization process produced a logical hierarchical output, where the smallest-diameter trees produced only material suitable for use as raw woodchip, whereas the bigger trees produced pulp, sawn timber and veneer log assortments, with larger diameters and lengths. The increment in DBH was consistent with the extension of timber assortment variety. The biggest change was observed between the DBH classes of 7 to 9 inches, where several veneer logs were detected.

Table 6
The estimated bucking results for different stem size samples.

	Number of assortment (logs) from a stem			
DBH, inches	Veneer	Sawn timber	Pulp log	Woodchips
1				residue
3			3	residue
5		1	4	residue
7	1	1	6	residue
9	4	2	4	residue

3.3. Scenario analysis of calculation

The results of case studies 1 and 2 indicate that an increment in average DBH of 3 to 5 inches will produce about 3-fold more tons per hectare in total. The yield of each assortment is presented in Table 8 for each test case. The increment is most notable for sawn timber. The following comparison between cases 2 and 3 shows that the DBH remained same when the density was reduced to 3x3-meter spacing. The yields of test case 3 were about one-third less for every assortment. On the other hand, when allowing the trees to grow to greater maturity, as in case 4, a good size of veneer log can also be achieved, and the quantity of pulp logs derived is remarkably high. The assumptions we made that informed our calculations need to be taken into consideration when these results are interpreted.

Table 8
Total yield (tons) for each assortment in each test case (1 ha).

Test case	Veneer	Sawn timber	Pulp	Wood chips	Total
CASE 1	0	0	49.9	5.2	55.0
CASE 2	0	82.4	88.2	5.1	175.7
CASE 3	0	54.9	58.8	3.4	117.1
CASE 4	45.4	70.3	175.6	2.7	294.1

The income, the harvesting and transportation costs, and the net revenue were calculated and are presented in Table 9 based on the amounts (in tons) of each assortment (Table 8) for each test case. The harvesting and transportation costs were determined based on current rates in the study area. The costs can be used to determine the net revenue of the harvesting operation. Our application allows the user to fix costs based on the current situation or exclude them all. The costs were approximately half of the revenue in cases 2, 3, and 4, whereas in case 1, they represented about 58%. The results of the comparison of case studies 1 and 2 indicate that a two-inch increment in DBH will lead to an almost 5-fold greater net income per hectare overall. On the contrary, a sparse tree density will lead to economic losses, because the net incomes were about 30% less in case 3 than in case 2. However, a mature-phase plantation (Case 4) with a sparse density yielded the highest net income—about 1.8- and 2.7-fold times greater than cases 2 and 3, respectively.

Table 9
Total incomes, harvesting costs, and revenues (THB) for each timber assortment in the test cases.

	Veneer	**Sawn timber**	**Pulp**	**Wood chips**	**Total**
	Revenue per assortment (THB)				
CASE 1	0	0	59,824	3,103	62,927
CASE 2	0	131,776	105,876	3,038	240,690
CASE 3	0	87,850	70,584	2,025	160,459
CASE 4	90,879	112,505	210,767	1,599	415,750
	Costs per assortment (THB)				
CASE 1	0	0	34,930	3,640	38,500
CASE 2	0	57,680	61,740	3,570	122,990
CASE 3	0	38,430	41,160	2,380	81,970
CASE 4	31,780	49,210	122,920	1,890	205,870
	Net income per assortment (THB)				
CASE 1	0	0	24,894	-537	24,357
CASE 2	0	74,096	44,136	-532	117,700
CASE 3	0	49,420	29,424	-355	78,489
CASE 4	59,099	63,295	87,847	-291	209,950

After ensuring the functionality of the scenario analysis, the mobile app for android phones was added to the Google Play platform for free downloading; the app user must simply add basic values of the tree data from the planned harvesting area, such as spacing, average DBH and size, to ultimately help them make decisions about harvesting and assortment selection.

4 Discussion

Figure 4 presents the flow of our study. The discussion deals with steps (1) to (5) from the point of view of the application user and research validation. Our initial aim was to provide information about eucalyptus forest management and to create a pragmatic decision support tool. Furthermore, the purpose was to enable the taking of measurements in the simplest way, without any specialized devices or tools, and which smallholders can perform by themselves. In plantation forestry, where eucalyptus is grown as a same-age monoculture, the tree sizes do not vary greatly if the growing conditions are homogenous (Cerqueira et al., 2019; Cerqueira et al., 2021). Additionally, the DBH also correlates strongly with the tree length and volume (Beets at al., 2012; Sanquetta et al., 2011; Ter-Mikaelian and Korzukhin, 1997). Under these circumstances, it is justifiable to assume that the DBH can be used as the parameter for estimating total timber mass when the area of the tree plantation and the spacing are known (1). The DBH of eucalyptus trees can be accurately defined by firstly measuring the girth and then transforming the value to the diameter. In Thai markets, inches are used to classify timber logs into different diameter classes, and so we selected the same metric for use in the mobile app. Using a measuring tape to measure spacing and the average DBH, a smallholder can input the required stand data into the EVO app (2).

(3) Our results indicate that both the spacing and the increment of DBH are significant factors when estimating the profitability of eucalyptus forestry. The spacing is determined at the planting phase, and there must be a balance between the density and the growth rate because increased density reduces the growth of individual trees at certain point of the tree rotation period. Our study covers only the most common density conditions, and therefore, our models can only be utilized under conditions with a normal spacing of trees. Additionally, planting patterns such as scattering around residences or linear planting around paddy fields may affect tree taper curves as well as volume. The EVO app represents a working platform on which users can see the estimated yield if harvesting were to be performed at this stage. The user can modify the input values and simulate a situation in which, for example, the rotation time were to be prolonged, or the DBH were to be one inch greater. However, the available tons is the most basic information regarding the harvesting area, and more supported and detailed information is required. The dynamic programming applied to timber bucking has played a key role in this development.

(4) The aim of this study was to increase the value of eucalyptus forestry using dynamic programming to assess alternative scenarios in which eucalyptus stems are bucked into different assortments based on DBH size and values such as THB per ton. This was made possible following the creation of taper models. As limited stem data were collected from plantations with different conditions, the R^2 value level was affected, and this manifested visually in the taper curves. Precise models were not the aim of this study, and instead, we sought to provide adequate models for use on the mobile application. An adequate level was achieved by the verification process, whereby more stem data were added. This happened in the most common tree size classes. The bucking patterns we suggested are based on the current market prices in the studied area, as well as minimum log diameter requirements. This opens up possibilities for smallholders to derive a higher income from their plantation, as the mobile app calculates and suggests ready-made bucking patterns for stem level and can provide total revenue predictions. The decision-making related to bucking can be seen as the most significant factor in relation to both timber sellers attempting to maximize their income and the forestry industry seeking the best timber assortments on the market. The pricing of timber logs will steer the market toward the growth of the most desirable assortments (Bowers, and Punches, 2007).

In the final point, (5), we see that the optimal assortment at harvesting responds to the requirements of quality and quantity within the forest industry, wherein timber logs are bought at prices based on delivery and standing sale. The EVO app can calculate harvesting and transportation costs for each assortment, such that the timber seller can make the final decision as to proceeding via standing sale or selling at the delivered price, both of which are possible timber trade options in Thailand. Naturally, the local buyers will expect to pay a reasonable and correct price per ton for each assortment; otherwise, the full benefits of the mobile app will not have been realized. Optimally functioning markets benefit and encourage smallholders, who will be assured of the demand for bigger logs as well. In this case, they can be confident that there will be active buyers in future. This increases the security of capital for a longer time, given that higher incomes can be expected.

One limitation of our study is that the net present value calculation was not included in and enabled by the EVO calculations. Our initial idea was to only provide information about the present situation in the plantation under review, and to indicate what would happen if the smallholder were to prolong the rotation time so as to grow bigger trees for a higher income. The eucalyptus-based forest industry has developed various tree clones for use in different environments. Thus, it is difficult to create one unambiguous taper curve model for all clones. However, this study presents relatively well-fitting models for different clones. The variation between clones seems to particularly affect the heights of the trees, which will eventually distort the individual tree stems' total mass and volumetric estimations, as derived using the presented models.

5 Conclusions

The current situation is that Thai timber markets do not fully recognize different eucalyptus timber assortments. Our findings clearly indicate the economic benefits of prolonging the rotation, and thus enhancing the growth, of eucalyptus trees based on the minimum industrial wood dimensions. In an ideal situation, eucalyptus log assortments would be graded based on their diameter sizes, and forestry companies would declare the purchase prices on the market. Forestry companies currently sort their logs at the mill yard if this action is in support of their refinery operation. However, this may not be the most beneficial approach for smallholders, who sell their timber at bulk price (THB/ton). The EVO application provides a purpose-built solution to help Thai timber markets transform, yielding a situation wherein log diameter sizes can also be taken into consideration during pricing. Naturally, wood procurement organizations need to refine their purchasing system in relation to receiving sorted logs directly from haulage. The precise characterization of plantation properties is key to delivering appropriate timber products to markets and optimizing timber value, thus further improving the livelihoods of small-scale farmers. Our study also offers a solution that will contribute to mitigating climate change. When tree growers prolong their rotation plan by a couple of years, and the harvested trees are also partly used as veneer, sawn timber, and other high-value timber products, carbon sequestration can be maintained for decades, not just the matter of years achieved with pulp and paper products.

Declarations

Funding

This work was financially supported by the Office of the Ministry of Higher Education, Science, Research and Innovation, and Thailand Science Research and Innovation through the Kasetsart University Reinventing University Program 2022.

Conflict of interest The authors declare no conflict of interest.

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Figures

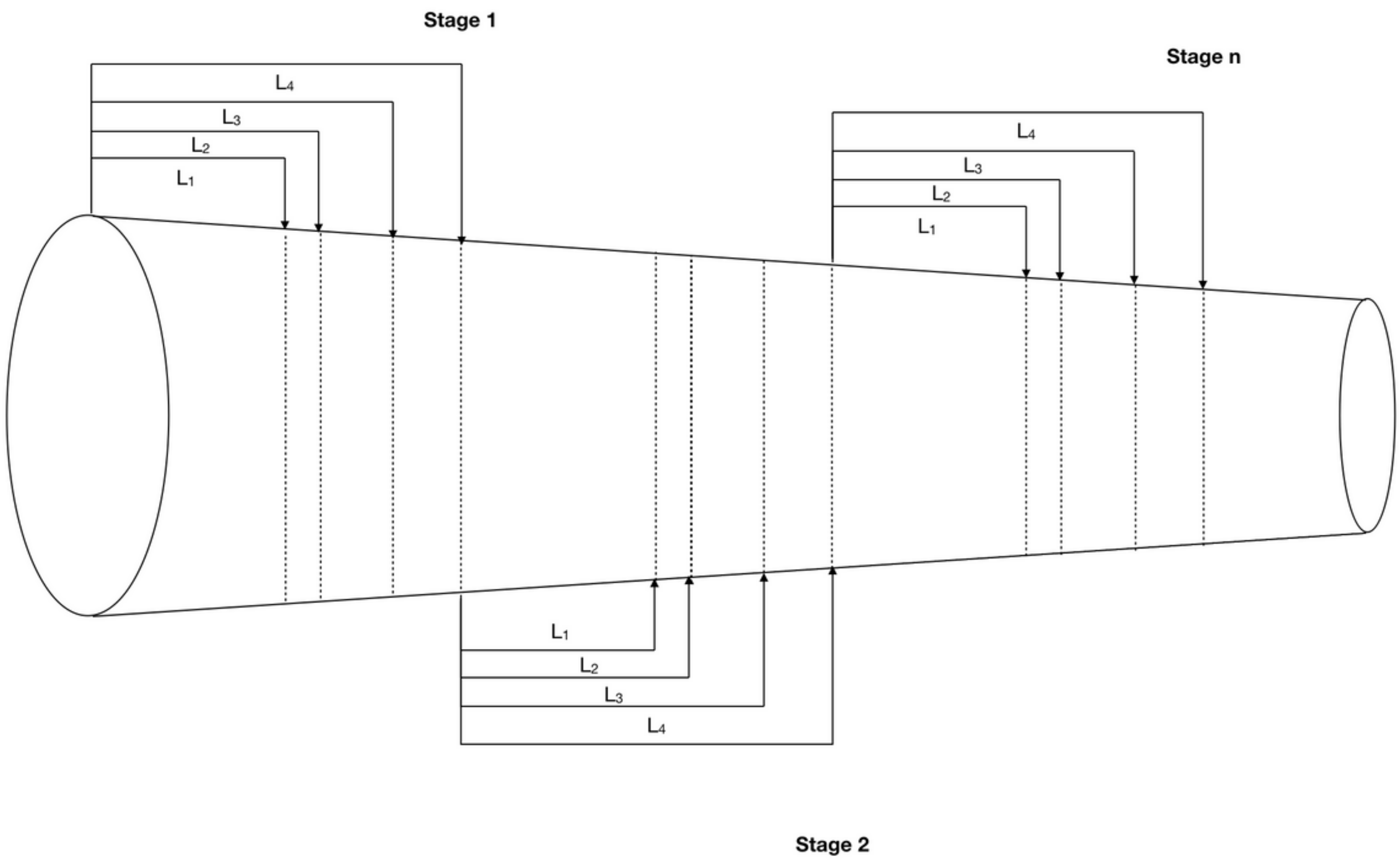

Figure 1

Dynamic approach to tree bucking applied in this study, presented as stages 1 to *n* (modified from Kivinen 2007).

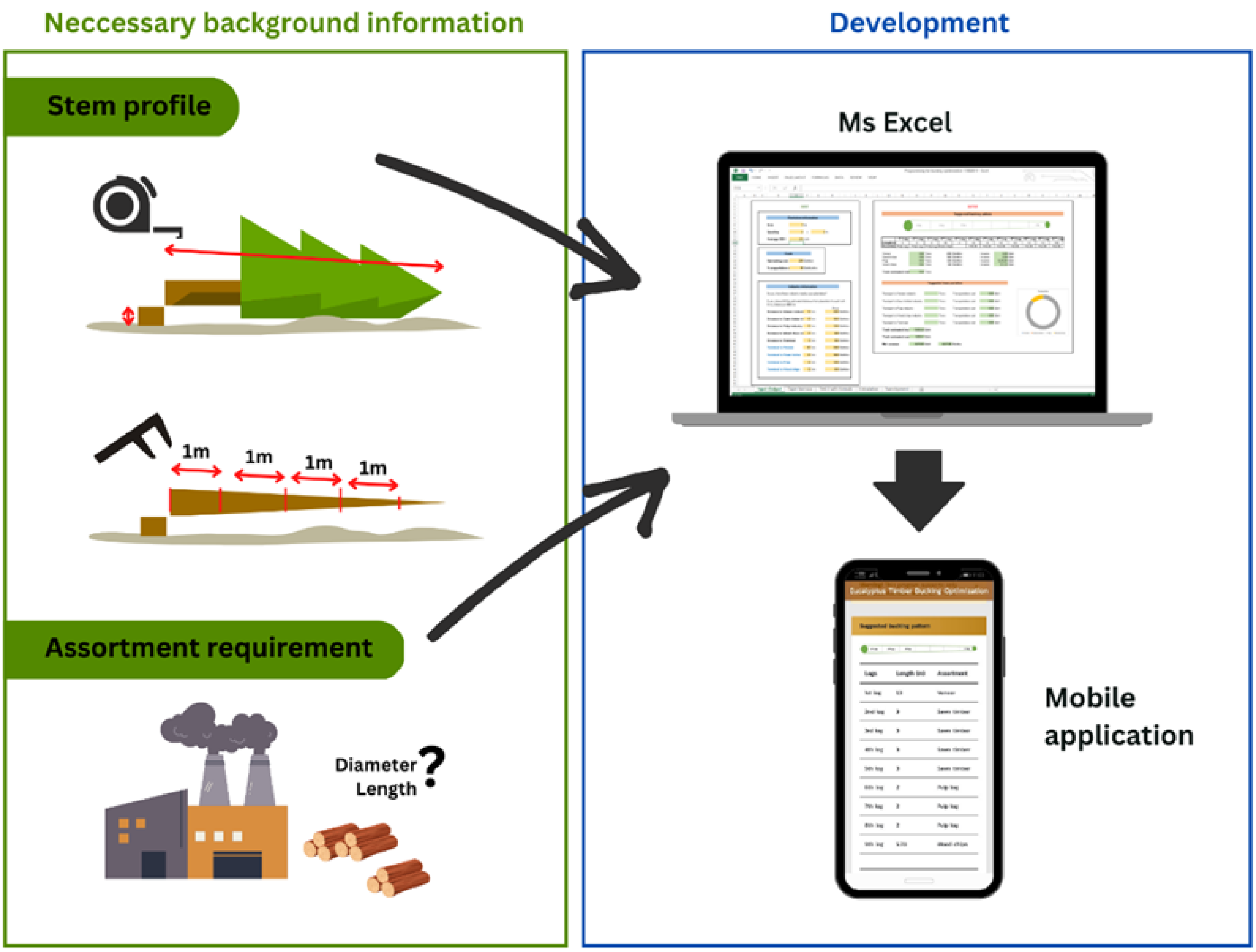

Figure 2

Main components of the study and the objective of the EVO mobile app development project.

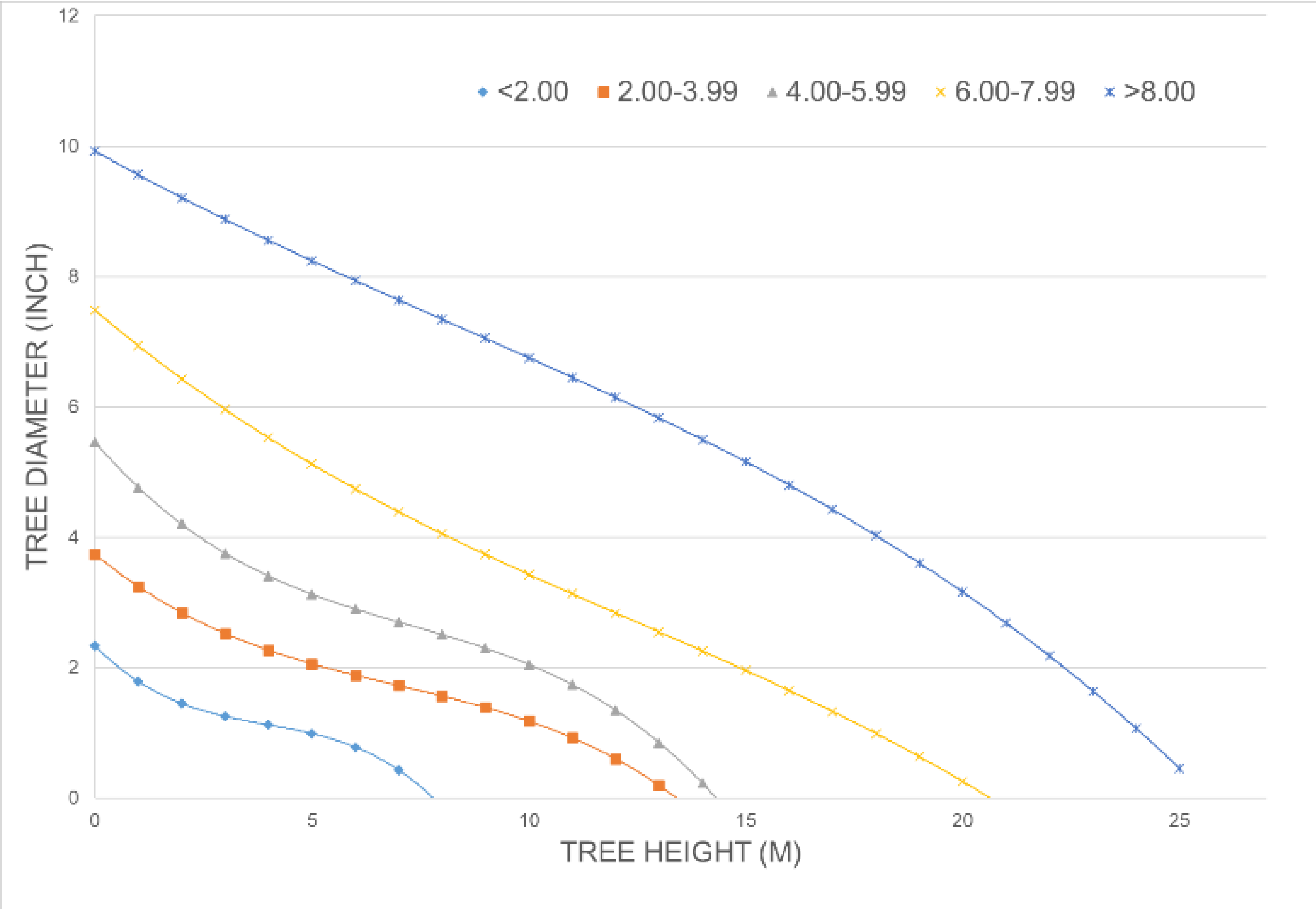

Figure 3

Tree taper curves for each diameter classes.

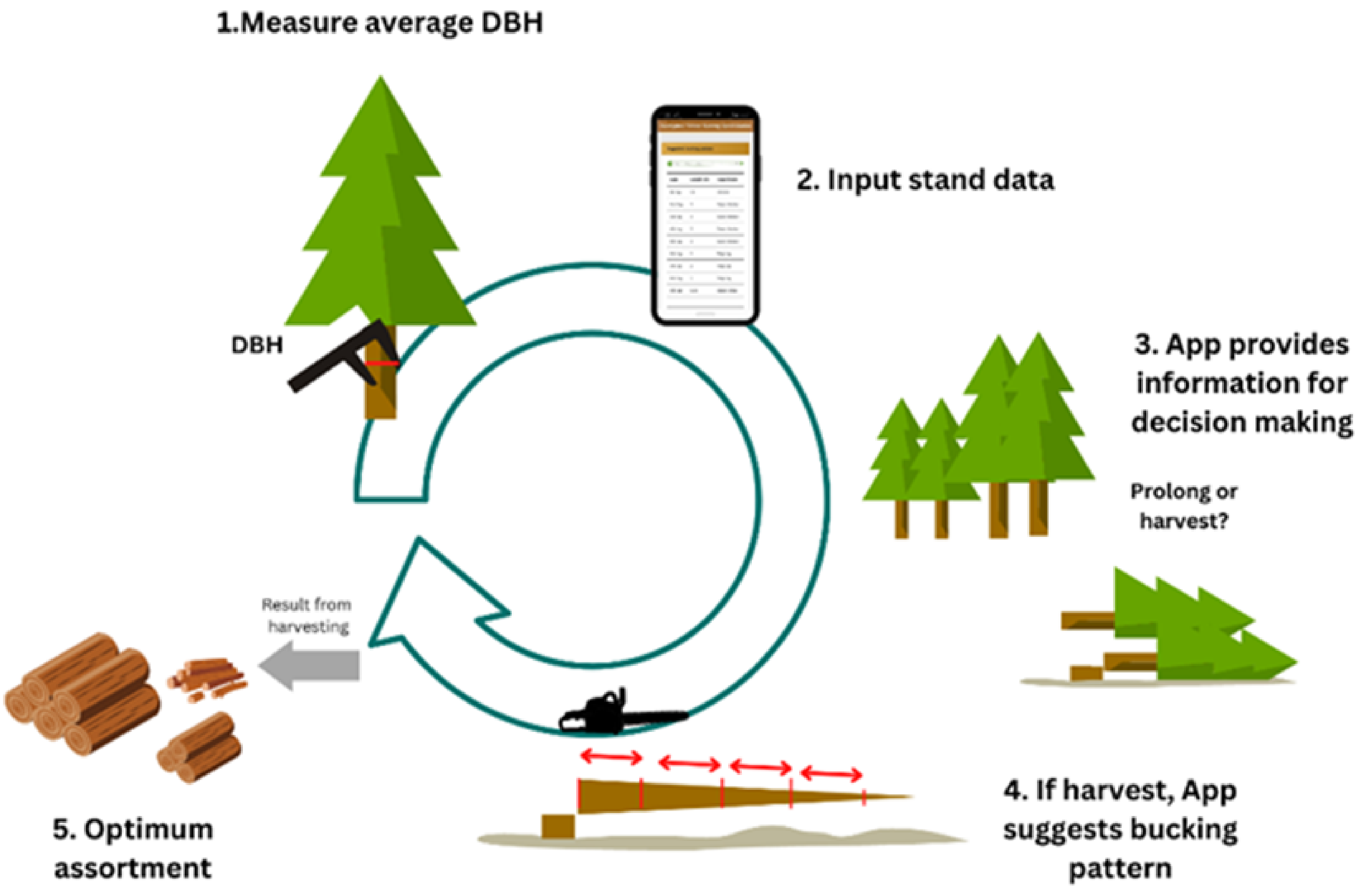

Figure 4

Process diagram of steps (1 to 5) for optimizing the yield using tree information and the mobile app.