Damage Cost/Value Clustering in Timber Harvesting Decision Making for Sustainable Forest Management

Original Scientific Paper

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Abstract *– The most important factor to ensure forest regrowth strongly relies on minimizing damage as well as maintaining an adequate quantity and quality of residual stands. Currently, most of the Malaysian concessions are applying the Selective Management System (SMS). The SMS had been introduced about 40 years ago and various studies discovered that it contributes a negative impact on the forest. Thus, revision and adoption of an appropriate harvesting method are required. The main objective of this study is to propose a new method that promotes forest regrowth and reduces damages due to logging activities for Sustainable Forest Management (SFM). The two primary elements introduce in this new method are 1) to determine the minimum damage cost/value to the residual trees according to tree felling direction and 2) on the division of logging area into clusters where only certain clusters will be affected in a logging operation and the rest are conserved. The overall results of this study proven that the analysis of potential logged value, productions, damage value, and damage volume by dividing forest into clusters able to minimize damage and maintain forest regeneration.*

Keywords*: damage cost/value, tree felling direction, forest clustering algorithm*

1. INTRODUCTION

Forests are crucial in terms of biodiversity and ecosystem, it gives numerous benefits to humans as well as timber products and biodiversity conservation. About 300 to 350 million people are directly and indirectly dependent on forests [1]. Tropical deforestation and forest degradation are some of the world's most urgent environmental problems. It contributes to biodiversity loss, accounts for approximately 17% of total global carbon emissions, and has adverse socio-economic consequences for forest-dependent people (e.g. EU, 2016). In addition, tropical forest degradation is one of the significant factors of carbon dioxide (CO_2) emission [2]–[4] approximately 2.1 billion tons of CO_2 yearly [2]. To address this issue, one of the crucial decisions to make in forest planning and forest management is to determine the best logging operation to increase timber harvesting productivity that reduces damages and promotes forest regrowth for sustainable forest management. In this paper, we describe the newly proposed methods to promote forest regrowth and reduce damages due to logging activities for sustainable forest management. By understanding the calculation of minimum damage based on tree felling direction, we can expect to have significant results in implementing the new methods and algorithms.

This paper is organized as follows; in the next section, the related work regarding the implementation and the limitations of the Selective Management System (SMS) are presented. Then followed by Section 3 where the newly proposed algorithms on how to determine the minimum damage cost to residual trees and also forest clustering for preservation are thoroughly described. Section 4 combines the results from the selection of the best-felling direction and decision-making on the minimum damage. Finally, Section 5 and 6 presents our conclusion and acknowledgment respectively.

2. RELATED WORK

Since 1978, the Selective Management System (SMS) was implemented for timber harvesting in Malaysia. This commercial logging system mainly targets dipterocarp species. Selective Management System (SMS), the current logging system is; a year before felling, commercially viable trees are marked for felling, the harvestable trees applied are >45 cm dbh for non-dipterocarp, and >50 cm dbh for dipterocarp species. Later, arrows are painted on trees to indicate the direction of felling to avoid damaging other valuable trees. Then, the system calculates the damage volume of residual trees [5], [6]. However, this event only takes place 10% of the pre-felling inventory as sampling for the rest of the felling area [7]. These decisions play an important role in maintaining the species composition and structure of the forest [8], [9].

According to various researchers [7], [8], [10]–[13], the most important factor to ensure forest regrowth strongly relies on minimizing damage as well as maintaining an adequate quantity and quality of residual stands. These studies discovered that the current selective logging contributes negative impacts to the forest; such as frequency distribution of gap area was strongly skewed, a low recovery rate of forest conditions after logging, tree volume of non-dipterocarp species higher than dipterocarp species, and absence of large-sized mammals. Therefore, a revision of current forest management in Peninsular Malaysia, mitigation actions, and the adoption of an appropriate harvesting plan for sustainable forest management are needed.

The purpose of this study is to propose a solution that has the potential to mitigate the stated current issues corresponding to sustainable forest management practices by dividing the forest into clusters, determine potential trees to log according to clusters with minimum damage value and damage volume to the surrounding trees. The analysis of these minimum damages provides a significant impact on forest preservation. The study will produce an output of the analysis that could be used by the government for timber harvesting decision-making.

3. MATERIALS AND METHOD

In response to this challenge, the main objective of this study is to propose a new method that promotes forest regrowth and reduces damages due to logging activities for Sustainable Forest Management (SFM). The two primary elements introduce in this new method are 1) to determine the minimum damage cost/value to the residual trees and 2) forest clustering to retain areas of unlogged forest for preservation. Preserve unlogged forest is critically important to safeguard species biodiversity of the tropical rainforest [7], [14], [15].

Selective Management System (SMS) is the current method that has been implemented by the majority of Malaysian concessions. Although this method is based on SFM practices, there are some negative side effects to the forest after more than 40 years of practicing.

For the logging activities, the SMS can be categorized into 3 stages for the logging activities under the SMS system. Table 1 describes the Selective Management System (SMS) that has been employing in a Malaysian forest. One of the limitations of this practice; these activities only take place on 10% of the whole logging area. From the accuracies point of view, this 10% sampling is no longer practical. Therefore, a new method is required.

The stages and activities according to the current practice are well illustrated.

Table 1. The SMS activities

Stage	Year	Activities
Pre-Harvesting	n-2 years to n-1 years	Pre-felling forest inventory of 10% sampling intensity using systematic-line plots to determine appropriate cutting regimes (>45 cm dbh for non-dipterocarp and >50 cm dbh for dipterocarp).
	n-1 year to n	Tree marking incorporating directional felling.
Harvesting	n	Felling all marked trees.
Post-Harvesting	n + ¼ year to n ½ year	Forest survey to determine fines on trees unfelled, royalty on short logs and tops, and damage residual stands.
	n + 2 year to n + 5 year	Post-felling inventory of 10% inventory using systematic-line plots to determine residual stocking and appropriate silvicultural treatments.
	n+10 years	Forest inventory of regenerated forest to determine the status of the forest.

The newly proposed solution has the potential to improve the current method. Table 2 is the general algorithm of the new method.

Table 2. The Algorithm of the New Proposed Method.

Calculates Volume and Value of each Tree in Logging Area
Step 1: Read ***idno, speciesName, speciesGroup, dbh, height*** from the tree mapping pre-felling table.
Step 2: Calculate the volume. $volume = \pi(dbh/2)^2\ height;$

Step 3: Calculate the value.

```
priceValue=
        "select priceValue from treeValue
        where speciesName=' sN' ";
value= volume .priceValue;
```

Calculates Threshold Value (The Maximum Allowable Harvest)

Step 4: Prompt and get the logging area.

Step 5: Calculate the maximum allowable harvest.

threshold= logArea .30m^3;

Divides Forest into Clusters

Step 6: Determine the length (x) of the logging area and divide it into clusters.

```
begin_x="select x-coor from
        preFelling order by x-coor asc limit 1"
end_x="select x-coor from
        preFelling order by x-coor desc limit 1"
length_x = end_x -begin_x
num_x=(length_x)/50
clus_x=(length_x)/(num_x)
```

Step 7: Determine the length (y) of the logging area and divide it into clusters.

```
begin_y="select y-coor from
        preFelling order by y-coor asc limit 1"
end_y="select y-coor from
        preFelling order by y-coor desc limit 1"
length_y = end_y -begin_y
num_y=(length_y)/50
clus_y=(length_y)/(num_y)
```

Step 8: Determine the clusters.

```
set cno= 0
set begin_x =begin_x
set next_x=begin_x+clus_x
foreach num_x increment by 1
        set begin_y =begin_y
        set next_y =begin_y +clus_y
        foreach num_y increment by 1
            cno=cno+1
            cno(begin_x,next_x,begin_y,next_y)
            begin_y = next_y
            next_y = begin_y +clus_y
        begin_x =next_x
        next_x =begin_x +clus_x
```

Step 9: Calculate the number of trees, total value, total volume, and total damage volume based on 20 sets of cutting regimes for every cluster.

```
read and write 20 set of cutting regime to database
foreach set of cutting regime [nonDip,dip]
        create a table:earlyprediction_[nonDip][dip]
        foreach cno
            insert into earlyprediction_[nonDip][dip]
            select count(tree),sumValue,sumVolume,
            sumDamage(0.43(sumResidual))
            where (dbh_G3 || dbh_G4= nonDip)
            && (dbh_G1 || dbh_G2= dip)
```

Step 10: Calculate the AVERAGE of number of trees, total value, total volume, and total damage volume by cluster

```
foreach cno
    read 20 set of cutting regime
    foreach set of cutting regime [nonDip,dip]
        record="select cno,tree,value,volume,damage
        from earlyprediction_[nonDip,dip]
        where cluster=cno"
        foreach data in record
            accumulate tree,value,volume,damage
            determine the tree_average ,value_average ,
                volume_average ,damage_average
            insert into calculatedcluster (cno,tree_average,
                value_average,volume_average,damage_average)
```

Step 11: Sort and sum the records in table: calculatedcluster.

```
sorted="select * from calculatedcluster
order by damage_average asc"
    foreach record of sorted
    calculate Σtree_average,Σvalue_average,Σvolume_average,
    Σdamage_average
```

Step 12: Determine cluster to log and to retain based on the threshold value.

```
update status='L' where
Σvolume_average.calculatecluster≤thresholdValue
update status='R' where status IS NULL
```

Step 13: Determine trees to log based on the cutting regime for each harvestable cluster.

```
cutting regime="insert into treeCutingRegime
select cno,nondip,dip from calculatecluster
where damage=damage_minimum
& status='L'
trees to log="insert into treesToLog
select * from preFelling pf
inner join treeCuttingRegime ct
on ct.treeNo= pf.treeNo
retain trees ="insert into retainTrees
where not exists
(select*from treesToLog)
```

Step 14: Determine minimum damage value and minimum damage volume to residual trees.

```
trees ="select tree_coordinate from treesToLog"
foreach record in tree
determine the residual trees of felling_direction P1
P1_volume= Σ Volume_residualTrees
P1_value= Σ Value_residualTrees
determine the residual trees of felling_direction P2
P2_volume= Σ Volume_residualTrees
P2_value= Σ Value_residualTrees
determine the residual trees of felling_direction P3
P3_volume= Σ Volume_residualTrees
P3_value= Σ Value_residualTrees
determine the residual trees of felling_direction P4
P4_volume= Σ Volume_residualTrees
P4_value= Σ Value_residualTrees
decide tree felling direction:
minimum_value=minimum(P1_value,P2_value,P3_value,P4_value)
```

Firstly, the proposed solution requires a tree mapping pre-felling database that contains detailed information on trees in tropical forests of logging areas. The tree mapping pre-felling database stores the position of each tree (x,y coordinate), DBH (diameter-breast-height), the tree height, species group, and species name. There are about 7650 trees in 9 hectares of forest. The following Fig. 1 displays random of 20 tree records of pre-felling data.

idno	speciesname	g	dbh	height	x	y
4991	Kelandan	G2	2.99	1.61	222.68	40.53
3623	Pepauh	G4	23.19	4.87	162.39	129.96
2447	Kelandan	G2	23.97	4.11	127.11	114.13
6170	Mengkulang jari bulu	G3	1.93	2.34	60.35	216.9
2535	Pulai basong	G4	1.35	1.57	226.72	214.63
919	Giam rambai	G1	2.71	2.64	12.2	82.08
671	Otak udang	G4	30.18	17.81	32.62	234.66
3569	Jongkong	G5	1.34	1.65	99.34	10.36
3821	Asam pupoi	G3	14.85	5.28	222.09	280.6
6531	Kelumpang	G4	4.82	2.9	15.9	220.16
4693	Balau tembaga	G1	3.85	2.4	254.57	220.09
820	Jongkong	G5	41.56	16.31	90.15	6.01
2369	Buluh	G5	3.23	3	181.8	24.15
7580	Damar hitam bulu	G1	4.91	2.39	25.4	30.06
6137	Durian tupai	G3	3.6	1.74	248.49	146.96
6681	Kelandan	G2	4.11	2.65	27.96	234.91
1339	Keruing gombang	G1	1.08	2.86	225.36	232.87
6880	Merawan daun bulat	G1	3.48	2.99	88.78	59.66
1101	Gapis	G4	3.86	1.29	270.49	96.28
3312	Babai	G5	3.41	2.42	254.54	74.09

Fig. 1. Trees pre-felling data.

Compares to the SMS; that only takes 10% sampling. This study records each tree in the logging area. Therefore, there are various constructive calculations, simulations, and analyses that can be performed using this tree mapping pre-felling records.

At first, before the division of the logging area into clusters, the volume (in m^3) and value (in RM) of each tree are calculated. Next, the threshold value is determined according to the size of the logging area. The maximum allowable harvest is $30m^3$ per hectare [16] and the threshold value for 9 hectares is $270m^3$.

Provided with the tree coordinates; the algorithm is designed and executed to determine the logging area which later divides it into clusters. Fig. 2 shows that 9 hectares of forest with a width of 300m and length of 300m are divided into 36 clusters. The size of a cluster is 50m in width and 50m in length [17]. While Fig. 3 presents the detailed position of each cluster.

It is hard to do a comparison between tree to tree of voluminous forest data. Therefore, this study takes into consideration dividing the forest into standard clusters/plots. It appeared that it is more practical and relevant to assess and analyze when data is group and divided accordingly.

Step 9 describes that the algorithm read 20 sets of cutting regimes as shown in Table 3. The algorithm creates 20 tables for 20 cutting regimes and each table consists of 36 records for 36 clusters. Each record in the table store the cluster number, total number of trees, total volume (production), total value, and total damage of residual trees (*there are about 43% of residual trees damaged after harvest [18]*) of potential trees to be harvested according to the specific cutting regime.

Later, the algorithm checks and summarize across all 36 clusters from the 20 tables in Step 9 and calculates the average, accumulate, and sort: number of trees, tree volume, tree value, and damages of residual trees. These records are stored in a dedicated table (*calculatedcluster*).

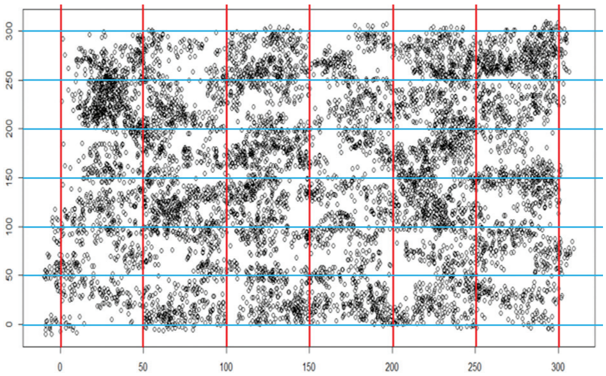

Fig. 2. 9 hectares of logging area is divided into 36 clusters.

cno	begin_x	end_x	begin_y	end_y
1	-9.64	43.52	-9.89	43.31
2	-9.64	43.52	43.32	96.52
3	-9.64	43.52	96.53	149.73
4	-9.64	43.52	149.74	202.94
5	-9.64	43.52	202.95	256.15
6	-9.64	43.52	256.16	309.36
7	43.53	96.69	-9.89	43.31
8	43.53	96.69	43.32	96.52
9	43.53	96.69	96.53	149.73
10	43.53	96.69	149.74	202.94
11	43.53	96.69	202.95	256.15
12	43.53	96.69	256.16	309.36
13	96.7	149.86	-9.89	43.31
14	96.7	149.86	43.32	96.52
15	96.7	149.86	96.53	149.73
16	96.7	149.86	149.74	202.94
17	96.7	149.86	202.95	256.15
18	96.7	149.86	256.16	309.36
19	149.87	203.03	-9.89	43.31
20	149.87	203.03	43.32	96.52
21	149.87	203.03	96.53	149.73
22	149.87	203.03	149.74	202.94
23	149.87	203.03	202.95	256.15
24	149.87	203.03	256.16	309.36
25	203.04	256.2	-9.89	43.31
26	203.04	256.2	43.32	96.52
27	203.04	256.2	96.53	149.73
28	203.04	256.2	149.74	202.94
29	203.04	256.2	202.95	256.15
30	203.04	256.2	256.16	309.36
31	256.21	309.37	-9.89	43.31
32	256.21	309.37	43.32	96.52
33	256.21	309.37	96.53	149.73
34	256.21	309.37	149.74	202.94
35	256.21	309.37	202.95	256.15
36	256.21	309.37	256.16	309.36

Fig. 3. Cluster number and the detail positions.

The *calculatedcluster* table shows the simplified records in a form of the total and average; the number of trees, value, volume, and damage of each cluster of overall 20 sets cutting regime. Referring to this table; potential harvestable clusters are determined based on the threshold value or the maximum harvestable volume (production) as shown in the algorithm of Step 12. Meanwhile, the clusters to be preserved are updated to status = 'R'.

Table 3. 20 sets of Cutting Regime

No.	Non-Dipterocarp (dbh in cm) [nonDip]	Dipterocarp (dbh in cm) [dip]
1	45	50
2	45	55
3	45	60
4	45	65
5	50	50
6	50	55
7	50	60
8	50	65
9	55	50
10	55	55
11	55	60
12	55	65
13	60	50
14	60	55
15	60	60
16	60	65
17	65	50
18	65	55
19	65	60
20	65	65

Once the potential clusters to be harvested are finalized. The algorithm selects the best cutting regime for each potential cluster. The selection is based on the cutting regime which yields the minimum damage to residual trees. Then, in Step 13 the algorithm able to identify the potential harvestable trees according to the selected cutting regime based on the clusters to be harvested which is determined in Step 12.

In addition to the series of steps in deciding the potential harvestable trees, the new timber harvesting techniques that we introduce also determine the direction of the felling tree which yields the minimum damage volume and the minimum damage value to the residual trees. Apart from the calculation on damage volume, calculation on damage value (in monetary value) is also included.

This study able to determine which felling direction yields the minimum damage cost and minimum damage volume to the surrounding trees. This method takes into consideration of various tree species, tree value, and tree volume of the trees that surround the potential tree to be harvested. There are only a few studies that produce and analyze the damages in terms of monetary values to the residual trees.

To determine the minimum damage cost/value and minimum volume of the residual trees. Total values and volumes of all affected residual trees due to the felling direction of a harvestable tree are calculated. In this study, there are 4 options for the felling direction of a harvestable tree. Fig. 5 shows the Part 1, Part 2, Part 3, and Part 4 felling directions of each harvestable tree. The algorithm is designed and executed to verify which felling direction that produces the minimum damage cost and minimum damage volume to the surrounding of the harvestable tree.

cno	no	x	y	dbh	volume	value
9	10	57.12	149.28	61.45	7.79	3129.6
9	26	54.42	144.11	38.1	3.27	1313.08
9	33	75.04	114.7	38.74	1.54	837.69
9	50	78.27	122.26	40.4	1.89	1031.88
9	52	68.29	143.3	42.22	3.13	1257.29
9	101	89.21	128.23	44.89	1.79	974.68
9	121	67.78	145.73	82.45	8.61	6924.07
9	151	87.62	100.98	84.61	4.97	2708.83
9	178	61.32	118.64	81.57	12.31	4949.4
9	194	81.81	121.71	34.06	1.74	698.85
9	293	67.92	125.46	40.62	2.92	1174.22
9	302	96.17	144.31	54.46	2.97	1195.81
9	362	48.4	135.77	31.82	1.95	783.22
9	365	56.11	129.79	86.39	8.48	3409.66
9	377	65.34	114.73	80.35	10.65	4280.62
9	396	51.14	99.05	51.09	1.97	792.8
9	397	67.81	123.98	66.38	6.11	2456.86
9	406	68.09	128.88	61.17	4.32	1735.46
9	446	90.2	99.39	78.75	6.54	2627.66
9	456	51.08	129.67	35.28	1.17	471.97
9	474	55.07	120.86	41.78	3.39	1379.89
9	511	85.96	127.58	49.24	2.34	940.81
9	596	90.74	112.13	58.18	3.89	1565.67
9	618	50.74	124.03	82.06	12.42	5056.27
9	624	55.58	108.94	70.61	9.07	3645.75
9	659	62.52	101.59	32.45	1.05	423.56
9	662	87.76	133.37	33.95	0.76	307.14

Fig. 4. Cluster No. 9 trees volume and value.

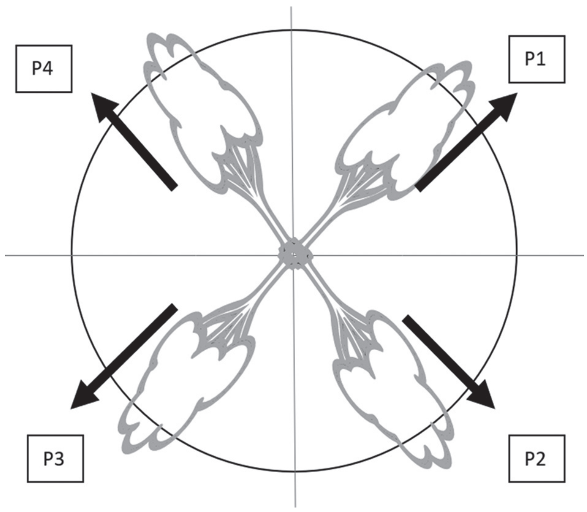

Fig. 5. The 4 options of felling.

no	speciesname	value	speciesgroup
1	Giam hantu	407	G1
2	Kapur	549	G1
3	Keruing bukit	545	G1
4	Meranti batu	402	G1
5	Balau membatu jantan	407	G1
6	Merawan batu	402	G1
7	Keruing kertas	545	G1
8	Balau bukit	407	G1
9	Merawan penak	402	G1
10	Meranti merah muda	732	G1
11	Chengal	1182	G1
12	Meranti paya	402	G1
13	Mersawa durian	626	G1
14	Keruing ropol	545	G1
15	Merawan mata kucing bukit	402	G1

Fig. 6. The tree species name, value (in RM per $1m^3$), and tree group.

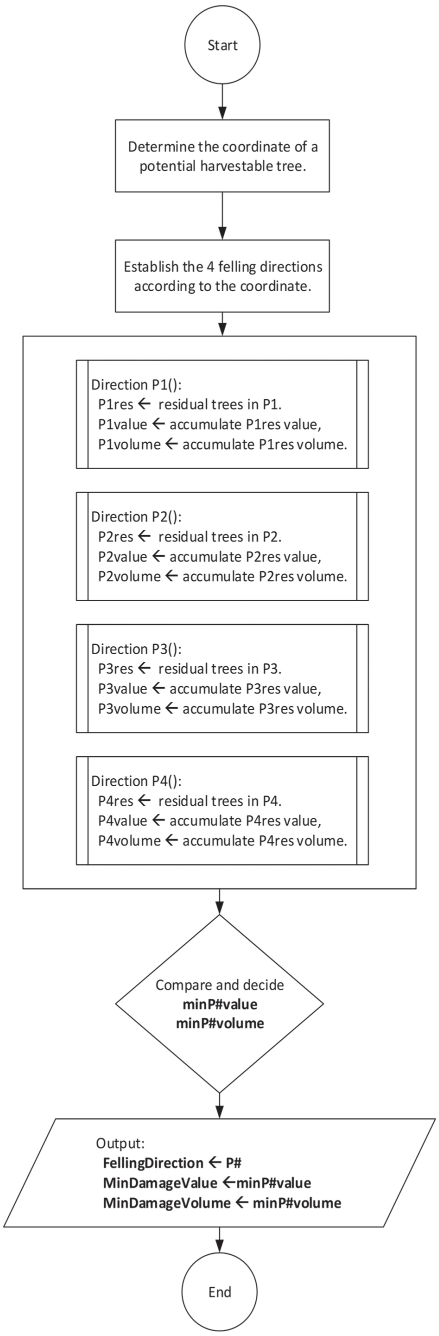

Fig. 7. Flowchart to determine minimum damage value and minimum damage volume.

For the damages calculation, at first, the algorithm will determine surrounding trees and verify them into Part 1, Part 2, Part 3, and Part 4 based on their coordinates. Later for each Part or felling direction, the algorithm calculates the total volume and value of residual trees included in it. The felling direction of the harvestable tree is based on the most minimum damage value between Part 1, Part 2, Part 3, and Part 4. The flowchart in Fig. 7 demonstrates the process of this calculation.

4. RESULT AND DISCUSSION

In this study, 7650 trees in 9 hectares had been recorded to determine the minimum damage value and minimum damage volume of the potential harvestable trees. The system has to select the best-felling direction before forming the calculation of minimum damage value and minimum damage volume. Fig. 8 shows that the system determines the felling direction of tree number 38; tree species name *Giam Rambai* is P3 (Part 3). The decision-making is based on the minimum damage volume and minimum damage value of the residual trees. This technique takes into account the various tree species, volumes, and values of surrounding affected trees.

no	x	y	name	dbh	vol	val	dmgvol	dmgval	direct
38	5.78	92.02	Giam rambai	54.08	2.97	1207.87	0.18	77.46	P3

mysql> select * from realexecution_fellingdirection;

fellno	speciesname	speciesgroup	x	y	dbh	height	volume	value	status
38	Giam rambai	G1	5.78	92.02	54.08	12.92	2.97	1207.87	M30
367	Kelandan	G2	7.15	92.88	58.88	22.54	6.14	2467.21	M30
501	Penarahan arang	G3	13.44	82.58	64.37	22.59	7.35	2955.28	M30
767	Jelawai mentalun	G4	13.2	93.81	67.09	8.08	2.86	1148.27	M30
803	Pulai penipu paya	G4	1.08	102.42	33.85	16.9	1.52	611.39	M30
901	Giam rambai	G1	-3.11	94.51	1.76	1.26	0	0.12	SE
902	Giam rambai	G1	10.94	93.36	3.99	1.4	0	0.71	SE
903	Giam rambai	G1	14.05	100.65	3.97	2.66	0	1.34	SE
904	Giam rambai	G1	11.8	84.59	1.77	2.81	0	0.28	SE
905	Giam rambai	G1	-0.86	82.21	4.78	2.11	0	1.54	SE
906	Giam rambai	G1	13.65	96.82	1.75	2.92	0	0.29	SE
907	Giam rambai	G1	-0.11	85.13	4.64	1.34	0	0.92	SE
908	Giam rambai	G1	1.54	98.93	2.04	1.61	0	0.21	SE
909	Giam rambai	G1	1.72	92.38	3.42	1.77	0	0.66	SE
910	Giam rambai	G1	12.33	101.63	2.97	1.46	0	0.41	SE
911	Giam rambai	G1	-2.09	84	1.4	2.42	0	0.15	SE
912	Giam rambai	G1	7.62	101.79	4.76	2.27	0	1.64	SE
913	Giam rambai	G1	-1.41	96.23	4.66	1.83	0	1.27	SE
914	Giam rambai	G1	10.65	95.82	2.18	2.38	0	0.36	SE
915	Giam rambai	G1	15.68	93.5	1.85	1.85	0	0.2	SE
916	Giam rambai	G1	14.44	95.89	3.98	1.58	0	0.8	SE
917	Giam rambai	G1	9.93	85.23	3.84	2.05	0	0.97	SE
918	Giam rambai	G1	11.77	100.9	4.9	1.72	0	1.32	SE
919	Giam rambai	G1	12.2	82.08	2.71	2.64	0	0.62	SE
920	Giam rambai	G1	1.39	91.11	3.62	1.73	0	0.72	SE

Fig. 8. Felling direction of tree number 38.

An iteration of this algorithm is designed to calculate and determine the minimum damage volume and minimum damage value of each harvestable tree to decide on the tree felling direction. Next, the algorithm produces the total number of felling trees, the total value of felling trees, the total damage volume (production), and the total damage value (damage) by the cluster as shown in Fig. 9.

cno	treenum	value	volume	damage
1	9	22352.13	51.44	12.1
2	13	31356.86	74.48	8.18
3	7	18741.01	45.67	8
4	12	38162.93	88.53	7.19
5	13	48521.95	100.99	12.13
6	13	40712.49	89.41	8.7
7	11	25655.23	59.59	10.58
8	10	24175.57	59.86	8.73
9	19	59140.05	136.57	18.43
10	16	39798.17	97.46	11.27
11	14	29958.67	71.91	13.39
12	10	23871.5	56.69	8.8
13	9	24482.18	59.84	9.96
14	12	34669.07	86.14	11.08
15	13	33382.47	71.82	16.56
16	9	32342.46	77.48	17.81
17	15	35833.61	88.89	13.8
18	10	22916.71	54.77	10.53
19	13	35708.76	87.4	9.92
20	15	51275.39	121.26	6.94
21	16	41875.33	100.35	13.65
22	9	16952.78	42.07	10.58
23	11	35415.85	77.47	9.88
24	10	36676.15	79.11	11.08
25	9	26227.82	60.12	10.95
26	10	27743.13	66.95	7.36
27	18	58442.13	142.29	11.79
28	10	22862.43	56.76	22.31
29	9	22379.6	55.46	12.41
30	15	40788.53	91.43	10.96
31	10	18415.63	43.51	5.35
32	8	22583.45	47.58	6.05
33	9	22859.98	54	5.11
34	7	15868.92	38.48	13.36
35	10	24030.57	52.51	17.08
36	17	52571.27	122.28	17.64

Fig. 9. Calculated the total number of felling trees, the total value of felling trees, the total damage volume, and the total damage value by clusters.

The newly proposed method introduces the logging area divided into clusters. Based on records shown in Fig. 9, the system descending sorts according to its value, production and ascending sort to its damage volume, and damage value by clusters. Then, the system accumulates those values as stated in Fig. 10.

This study proposed a new method by dividing the logging area into clusters and able to determine which tree to fell is based on the value of timber and minimum damage to the residual tree. With this new method, certain clusters will be preserved to maintain forest regeneration.

Referring to the threshold value (*maximum allowable harvest = 270m^3 for 9-hectare forest*), the system then calculated and only trees within 4 clusters are affected for a logging operation as shown in Fig. 11.

cno	totaltree	totalvalue	totalvolume	totaldamage
33	9	22859.98	54	5.11
31	19	41275.61	97.51	10.46
32	27	63859.06	145.09	16.51
20	42	115134.45	266.35	23.45
4	54	153297.38	354.88	30.64
26	64	181040.51	421.83	38
3	71	199781.52	467.5	46
2	84	231138.38	541.98	54.18
6	97	271850.87	631.39	62.88
8	107	296026.44	691.25	71.61
12	117	319897.94	747.94	80.41
23	128	355313.79	825.41	90.29
19	141	391022.55	912.81	100.21
13	150	415504.73	972.65	110.17
18	160	438421.44	1027.42	120.7
7	171	464076.67	1087.01	131.28
22	180	481029.45	1129.08	141.86
25	189	507257.27	1189.2	152.81
30	204	548045.8	1280.63	163.77
24	214	584721.95	1359.74	174.85
14	226	619391.02	1445.88	185.93
10	242	659189.19	1543.34	197.2
27	260	717631.32	1685.63	208.99
1	269	739983.45	1737.07	221.09
5	282	788505.4	1838.06	233.22
29	291	810885	1893.52	245.63
34	298	826753.92	1932	258.99
11	312	856712.59	2003.91	272.38
21	328	898587.92	2104.26	286.03
17	343	934421.53	2193.15	299.83
15	356	967804	2264.97	316.39
35	366	991834.57	2317.48	333.47
36	383	1044405.84	2439.76	351.11
16	392	1076748.3	2517.24	368.92
9	411	1135888.35	2653.81	387.35
28	421	1158750.78	2710.57	409.66

Fig. 10. Descending sort and accumulates trees, value, volume, and damage.

cno	treenum	value	production
20	15	51275.39	121.26
31	10	18415.63	43.51
32	8	22583.45	47.58
33	9	22859.98	54.00

Fig. 11. The affected clusters for logging operations.

5. CONCLUSION

The research introduces two new elements to be included in timber harvesting pre-felling analysis is to ensure forest regrowth which able to minimize damage as well as maintaining an adequate quantity and quality of residual stands. The first element that this research highlighted is to determine the minimum damage cost/value to the residual trees according to tree felling direction.

In addition, to retain areas of unlogged forest for preservation; this research focused on the division of logging area into clusters where only certain clusters will be affected in a logging operation and the rest are conserved.

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