Problem Chosen	2022 MCM/ICM Summary Sheet	Team Control Number
E		2226737

Carbon Sequestration: Optimized Forest Management Plan

With the continuous burning of fossil fuels, the amount of greenhouse gases released to the atmosphere is increasing, causing the crisis of climate change. Besides employing mechanical methods, which intervenes the nature by modern technology, plants can also sequester carbon and store them inside their body, thus reducing the amount of carbon dioxide in the atmosphere. This essay focuses on the carbon sequestration of trees and the optimum forest management plan, mathematical models developed to decide the optimum plan and test the result.

For the first model we exclude the factor of economic profit and only take into account the ecological benefit to decide the forest management plan. We consider it the difference between the sequestered carbon from the growing trees and the released from the death (burning) of past products. Since the latter cannot be decided by management plan, we mainly focus on the former, which is decided by species properties and harvest plan. We use differential equations to determine the sequestration amount function. We use the market and forest data in the past to calculate the released amount. It equals the sum of the harvested wood in year i multiplied by its consumption proportion in the market. Finally we develop an algorithm to give the optimum harvest location and range at any given time for any given forest.

Then we take into consideration the economic factor — the forest management department needs to balance carbon sequestration with economic growth. To unify their criteria, we use the data from Emission Trading System. In that way we transfer carbon sequestration to currency earned, thus solving the problem. By changing the function in the last algorithm, a new one is developed and can give the optimum management plan with both ecological and economic factor within consideration.

With the two models developed, we simulate a forest and apply the models to them. We let the forest be a square matrix and then impose a random offset on the trees. Then we randomly generate the tree properties under supervision, unreasonable ones discarded. We conduct sensitivity analysis on the two models and algorithms. Through this process, we get to know what actually affects the harvest plan, which is a four-dimensional vector. They both prove the viability of our models and algorithms.

At last we write a non-technical article to justify the tree harvest to the people. We use objective proof and the theory and thought of function to persuade those who do not have science or mathematical base knowledge. The article accords with our models and results, and is suitable for any normal person to read and understand the mechanism of it.

Contents

1 Introduction

1.1 Background

As is known to all, climate change can have a dramatic impact on lives. To mitigate its negative effect, measurements should be taken to reduce the CO_2 amount in the atmosphere. Besides mechanical means which affects the nature by modern technology, biosphere can also play an important role in restraining the negative climate impact. Trees can breathe in CO_2 and breathe out O_2 by photosynthesis, which plays an essential role in the reduction of greenhouse gases. Some forest products such as paper and furniture can also sequester CO_2 and some can even outlive the trees that produce them. Proper human management of forests protects the forests, maximizes photosynthesis and manage the production of forest products, thus realizing a best carbon sequestration. So an optimized forest management plan is critical.

Since proper tree harvest not only brings about economic benefits but also clears up space for saplings, it is not wise to leave the forest uncut forever. So an optimized forest management plan involves determination of tree harvest. What is needed is models which can determine an optimized plan for any given forest with relatively easy-obtained data, which is what we work on in this essay.

1.2 Our Work

Our goal is to determine an optimized forest management plan by creating mathematical models, test the model's robustness and the plan's performance.

1. **Create a model revealing the mechanism of the forest life cycle and determine the optimum forest management plan for any given forest.**
   (a) Justify tree harvest and reveal its superiority to no tree harvest.
   (b) Create functions describing the photosynthesis rate with data of age and species.
   (c) Describe the impact of tree harvest on carbon sequestration amount.
   (d) Determine the optimum time to harvest any tree given its species.
   (e) Determine the optimum harvest range center, length and width given the forest condition
2. **Add to the model the economic impact of tree harvest.**
   (a) Establish an algorithm to convert ecological values into currency.
   (b) Balance ecological and economic benefits and determine the optimum forest management plan for any given forest.
3. **Test and analyze the sensitivity of each parameter in the model.**
   (a) Conduct sensitivity analysis of each factor.
   (b) Determine the main factors affecting the optimum forest management plan and how they affects it.
4. **Apply our model to various forests.**

(a) Identify a forest that our model would suggest the inclusion of harvesting in its management plan.

2 Assumptions and Notation

2.1 Assumptions

1. However many times saplings are planted, the proportions of each tree species remain the same.

   Justification: This assumption favors our calculation. The biodiversity of the forest should be protected, thus justifying the assumption.

2. If a tree does not undergo photosynthesis from a certain time on, it dies at this time. When a tree dies, it will instantly be cut down, made into a certain product and replaced by a sapling.

   Justification: Since a dead tree can neither sequester CO_2 nor grow higher for a greater carbon sequestration, it should be cut down to allow a sapling to grow.

3. All tree species are invasive enough to form their concentrated colonies.

   Justification: To balance every tree's optimum harvest time, the considered area must be filled with a same tree species.

4. Sapling costs are obscure enough to be neglected.

   Justification: With the rapid development of techniques such as propagation, it will be very easy and not costly to obtain saplings.

5. The range of a harvest event is a rectangle.

   Justification: In real life, the range should be a geometry shape composed by several rectangles. If we consider it one rectangle, more accurate t is needed to obtain the same accuracy.

6. At any round of harvest, the proportion of wood harvested and made into a product equals the proportion of that product consumed in the overall consumption.

   Justification: It generally accords with the normal market strategy of a forest management department.

2.2 Notation

Symbols	Definitions
u_t	the number of trees in an area (usually the harvested area) at time t
t	the time from the start of calculation (unit: one average lifespan of the tree in the column)
t_i	the t when tree i is planted
Δt	the time span of model calculation

ϵ_t	the carbon price at time t (\$/(1000kg))
c_t	the wood price at time t (\$ $\cdot m^{-}3$)
ρ_i	density of tree i or its species ($kg \cdot m^{-2}$)
h	difference of the total height and crown height
d	the diameter at breast height of a tree
T_i	the difference between the t when tree i is harvested and the t when it is planted
l_j	the lifespan of product j
λ	a parameter indicating a tree's maximum ability to sequester carbon, which is decided by tree species
$v_i(t)$	the net photosynthesis rate of tree i at time t
p_i	the t when v_i reaches its maximum value, which is decided by tree species
$n_i(t)$	the amount of substance of sequestered CO_2 by tree i at time t
$n_{R,i}$	the amount of substance of CO_2 released to the air by tree i
n_S	the amount of substance of sequestered CO_2
$\alpha_{j,t}$	the proportion of wood harvested at time t and made into product j
$\beta_{j,t}$	the proportion of product j consumed at time i in the overall consumption at time t
$B(t)$	the overall benefit of the forest from the harvest event at time t

Table 1: Notation

3 Management Plan Optimization Model

3.1 Model Overview

This model reveals how the forest ecosystem works and how human activities affect it. We see forest of a given area as a set whose elements are *columns* where trees can grow. Since the columns are of equal weight and are calculated independently, only one column needs to be calculated. According to *Assumption* 2, the number of trees in any column at any time is 1. If not specially mentioned, only one column is discussed in the model and the species of the tree in the column is fixed.

3.2 Tree Features

Obviously

$$n(t) = \int v(t)\ dt$$

The function $v(x)$ should match the following features.

$$\begin{cases} (x-p)\cdot\frac{dv}{dx} \leq 0 \\ (x-p)\cdot\frac{d^2v}{dx^2} \leq 0 \\ v(0)=v(1)=0 \end{cases}$$

One function that matches those features is

$$v(x) = \frac{ax}{(x+p)^2}$$

where a indicates the photosynthesis ability of a mature tree. So when applied to the domain of forest management, it should be

$$v(t) = \frac{\lambda t}{(t+p)^2}$$

So

$$n(t) - C = \int v(t)\ dt = \lambda \ln{(t+p)} + \frac{\lambda p}{t+p}$$

$n(0)=0$, so

$$n(t) = \lambda \ln{(t+p)} + \frac{\lambda p}{t+p} - \lambda \ln p - \lambda$$

In the following figures, λ is modified to make $v(T)_{\max}$ the same, in order to favor visual comparison.

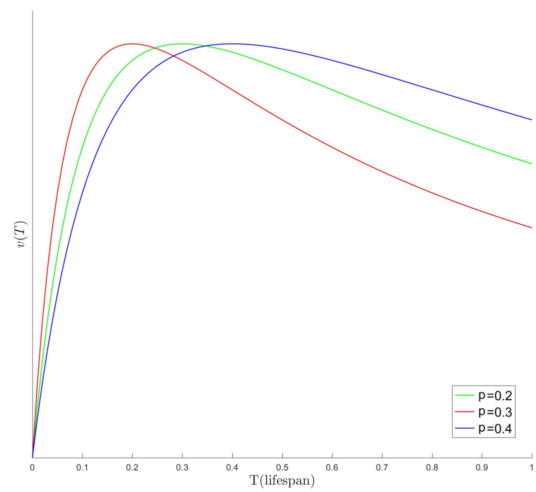

Figure 1: $v(T)$

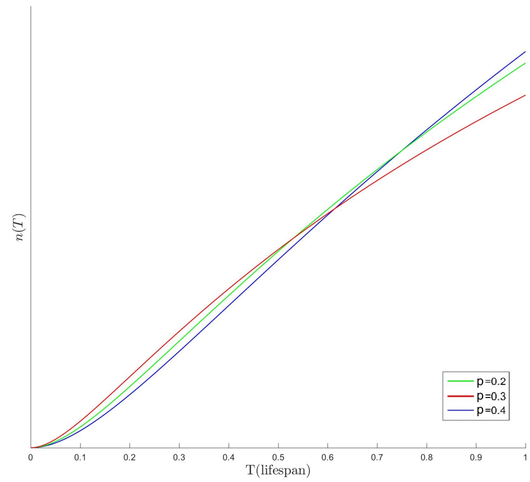

Figure 2: $n(T)$

3.3 Sequestration Amount

Since the $v(x)$ of a tree starts to decrease after its mature age (peak productivity), harvest it and replace it with a sapling may be a better choice, both ecologically and economically though the latter is not discussed in this model. Our first task is to determine the optimal time to harvest a tree given its species.

Due to *Assumption* 2, $T \in (0, 1]$. If the scale (Δt) is great enough, we can roughly estimate that the number of life cycles equals $\frac{\Delta t}{T}$.

$$\Sigma n = \frac{50}{T} \cdot n(T) = \frac{50\lambda}{T} \left(\frac{p}{T+p} + \ln{(T+p)} - \ln{(p)} - 1 \right)$$

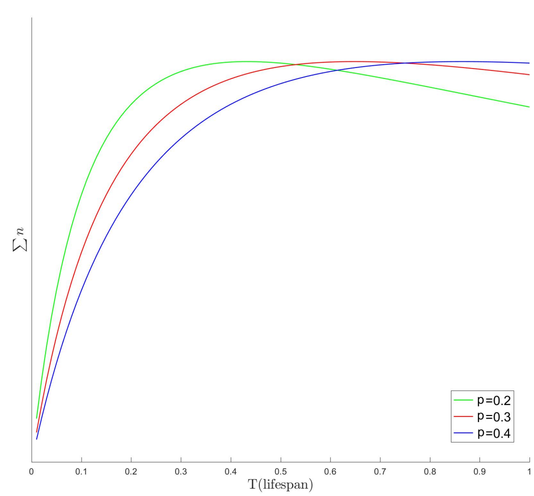

Figure 3: Σn

This function determines how much CO_2 one column sequesters in 50 lifespans.

So as for the total CO_2 the forest can sequester in any time span,

$$n_S = \sum_{i=1}^{u} \sum n_i$$

$$n_S = \sum_{i=1}^{u} \frac{\Delta t}{T} \cdot n(T_i), T_i = t - t_i$$

$$n_S = \sum_{i=1}^{u} \frac{\Delta t \cdot \lambda_i}{T} \left(\frac{p_i}{t - t_i + p_i} + \ln\left(t - t_i + p_i\right) - \ln\left(p_i\right) - 1 \right)$$

According to *Assumption* 3,

$$n_S = \frac{\lambda \cdot \Delta t}{T} \cdot \sum_{i=1}^{u} \left(\frac{p}{t - t_i + p} + \ln\left(t - t_i + p\right) \right) - u\left(\ln(p) + 1\right)$$

Our task is to calculate the maximum value of Σn and the T then. Stationary points are calculated below.

$$\frac{d}{dt} \cdot \Sigma n = 0$$

Simplified:

$$\frac{\frac{50p}{T+p} + 50\ln(T+p) - 50\ln p - 50}{T^2} = \frac{50}{(T+p)^2}$$

We yet cannot give the analytic solution for the equation. We let p equals some certain reasonable values and calculate the numerical solutions of the optimum T. The results are listed in the table below. Those solutions outside the domain of function are abandoned. A tree should not be harvested and replaced by a sapling before its mature age. So those $T \leq p$ are abandoned. If there is no solution, the smallest T bigger than 1 is shown and put between a pair of brackets. We fit a curve to observe the relationship between T and p.

p	T	T/p
0.1	0.2162581587	2.162581580
0.2	0.4325163185	2.162581592
0.3	0.6487744773	2.162581591
0.4	0.8650326347	2.162581587
0.5	(1.081290793)	(2.162581586)
0.6	(1.297548952)	(2.162581587)
0.7	(1.513807111)	(2.162581587)

Table 2: numeric solutions of T under different p and their relations

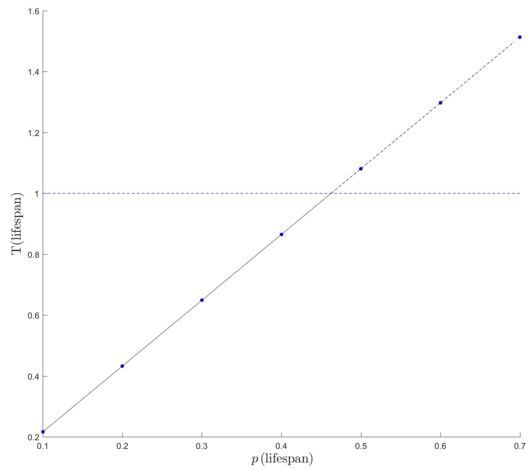

Figure 4: $p-T$ curve

We can estimate quite precisely that for the optimum harvest strategy,

$$T = 2.1625816 \cdot p$$

So when the optimum T exceeds 1, for the best ecological benefit, a tree should never be harvested until its natural death.

3.4 Released Amount

The released CO_2 comes from the death (burning) of the products produced during the past period. We estimate the n_R of product death with the consumption amount every year. For example, the data in 2019 can be obtained here.[3]

According to *Assumption* 6,

$$\alpha_{j,t} = \beta_{j,t}$$

We abstract the tree chunk into a cylinder. Thus,

$$m = \rho\pi\frac{d^2}{2} \cdot h = \frac{\rho\pi h d^2}{4}$$

We consider the carbon content of trees is fixed regardless of its species.[2]

$$m_{\text{carbon}} = \frac{\rho\pi h d^2}{8}$$

Since all element of carbon is burned to CO_2,

$$n_{R,i} = \frac{44}{12} \cdot m_{\text{carbon},i}$$

$$n_{R,i} = \frac{11\pi\rho}{24} \cdot \sum_{i=1}^{u} h_i d_i^2$$

We calculate the mathematical expectation of $n_{R,i}$ using any data from any time.

$$E(n_{R,i}) = \frac{\rho}{u} \cdot \sum_{i=1}^{u} h_i d_i^2$$

Consider the n_R when $t = 0$. (The relative t does not matter.)

$$n_R = \rho \cdot \sum_{\Delta t=0}^{+\infty} \sum_{l_j=\Delta t} \left(\left(\alpha_{j,-\Delta t} \cdot u_{-\Delta t} \right) \cdot E(n_{R,i}) \right)$$

$$n_R = \sum_{\Delta t=0}^{+\infty} \sum_{l_j=\Delta t} \left(\beta_{j,-\Delta t} \cdot \sum_{i=1}^{u_{-\Delta t}} h_i d_i^2 \right)$$

For any t, by the above-mentioned equation,

$$n_R = \rho \cdot \sum_{\Delta t=0}^{+\infty} \sum_{l_j=\Delta t} \left(\beta_{j,t-\Delta t} \cdot \sum_{i=1}^{u_{t-\Delta t}} h_i d_i^2 \right)$$

3.5 Net Sequestration Amount

When a tree is harvested, it will be turned to a product, carbon it has sequestered remaining until the product is dumped. Since the forest management has neither a start nor an end, we calculate the ecological benefit every time period (e.g. 10 years).

$$\text{Ecological Benefit}(\Delta n) = \text{Sequestered Amount} - \text{Released Amount}$$

So

$$\Delta n = n_S - n_R$$

$$\Delta n = \frac{\lambda \cdot \Delta t}{T} \cdot \sum_{i=1}^{u} \left(\frac{p}{t - t_i + p} + \ln(t - t_i + p) \right) - u\left(\ln(p) + 1\right) - \rho \cdot \sum_{\Delta t=0}^{+\infty} \sum_{l_j=\Delta t} \left(\beta_{j,t-\Delta t} \cdot \sum_{i=1}^{u_{t-\Delta t}} h_i d_i^2 \right)$$

3.6 Management Optimization Algorithm

Our forest management involves the properties of the harvest range. Obviously when a harvest occurs, trees in a continuous area are all cut down. According to *Assumption* 4 & 5, our aim is to determine the balanced harvest center, length and width for any t.

Our calculation focuses on those trees in the harvest range. Their net ecological profit should reach the maximum value.

$$B(t) = \sqrt{\frac{1}{u} \cdot \sum_{i=1}^{u} \left(\Sigma n(t - t_i) - \Sigma n(1) \right)}$$

We develop an algorithm to calculate the optimum T given the data of the forest. (See *Appendix A*.1) The algorithm involves 2 parameters, which need the forest management department to measure themselves. We write a user guide for the department. (See *Appendix B*) Since the parameter which is decided by tree species, after multiple operations (algebraic function, transcendental functions, calculus operations), can cause qualitative change, no fixed functions can satisfy our need. The algorithm is posted in appendix.

4 Ecologic & Economic Balance Model

4.1 Model Overview

Forest department mainly benefit from selling wood to wood factories. There is a balance point between economic income and carbon sequestration. This model aims at finding this point.

4.2 Ecological & Economic Balance

To decide the optimum management plan, we need to unify the measuring criteria for ecological & economic aspects. *Emission Trading System* is a good platform for it.[1]

$$B(t) = \text{Economic Benefit} + \epsilon_t \cdot \Delta n$$

Our model aims to calculate $B(t)$ with given harvest range properties and compare them. With given harvest range properties, economic benefit can be calculated. So

$$B(t) = c_t \cdot \sum_{i=1}^{u} \left(\pi h_i d_i^2\right) + \epsilon_t \cdot \Delta n$$

$$B(t) = \frac{\epsilon_t \cdot \lambda \cdot \Delta t}{T} \cdot \sum_{i=1}^{u} \left(\frac{p}{t - t_i + p} + \ln\left(t - t_i + p\right)\right) - \epsilon_t u \left(\ln(p) + 1\right)$$
$$-\epsilon_t \rho \cdot \sum_{\Delta t=0}^{+\infty} \sum_{l_j=\Delta t} \left(\beta_{j,t-\Delta t} \cdot \sum_{i=1}^{u_{t-\Delta t}} h_i d_i^2\right) + \pi c_t \cdot \sum_{i=1}^{u} h_i d_i^2$$

4.3 Ecological & Economic Balance Algorithm

Inputting the data of the trees (forest), the algorithm will return the optimum center, length and width of the harvest range. (See *Appendix A*.2) For the same reason with Management Optimization, we cannot give the analytic solutions.

5 Model Application

5.1 Local Notation

Symbols	Definitions
MOA	Management Optimization Algorithm
EEBA	Ecological & Economic Balance Algorithm

Table 3: Model Application Notation

5.2 Forest Initialization

No open dataset of forests which are big enough is found, so we simulate an area of forest where trees are all of the same species to test our model.

We create a 250m $\times$ 250m square for the initialization of the forest we simulate. 30×30 dots are averagely placed on the square. Then we impose a random offset on each point (tree). Other data are created randomly but under supervision. Unreasonable values are discarded and recreated. Thus a reasonable simulation of a forest is generated and initialized. One outcome of the random offset is shown below.

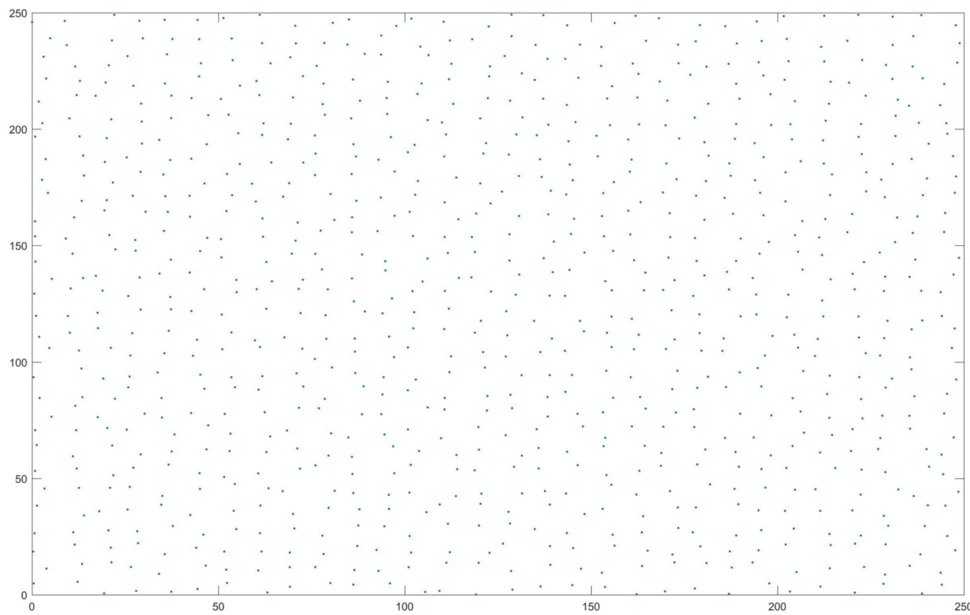

Figure 5: A forest randomly generated under supervision

5.3 Application Result

We apply the forest data to our algorithms. The results are shown below.

	x start	x end	y start	y end
MOA	199	221	149	171
EEBA	1	29	71	247

Table 4: Algorithm results

5.4 Indirect Results

There are some values which the algorithm itself does not output, can be calculated with the results and parameters, but have real life meanings and values. Here are listed the top 5 forest management plans of MOA & EEBA

x start	x end	y start	y end	$(t)_{max}$
199	221	149	171	30.8504
123	145	179	201	30.2965
121	145	179	201	30.2965
121	143	179	201	30.2965
119	145	179	201	30.2965

Table 5: MOA Top 5

x start	x end	y start	y end	$B(t)_{max}$
53	167	217	239	71772
55	165	217	239	71772
55	167	217	239	71772
81	165	217	239	71140.2
81	167	217	239	71140.2

Table 6: EEBA Top 5

6 Sensitivity Analysis

6.1 Management Plan Optimization Model

(1) λ (not sensitive)

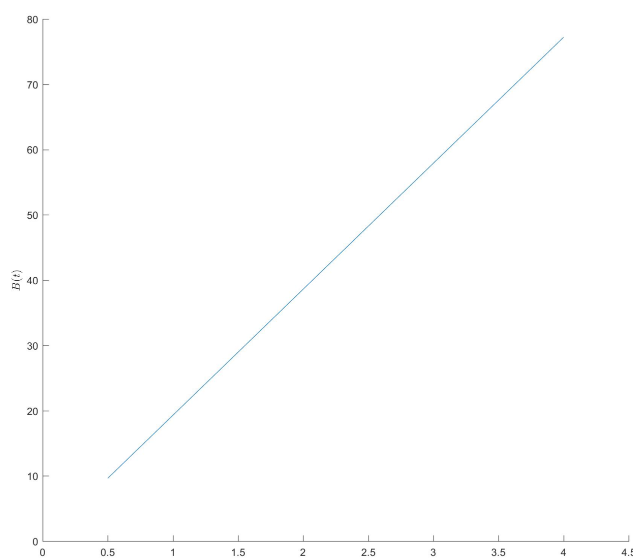

Figure 6: λ

(2) p (not sensitive)

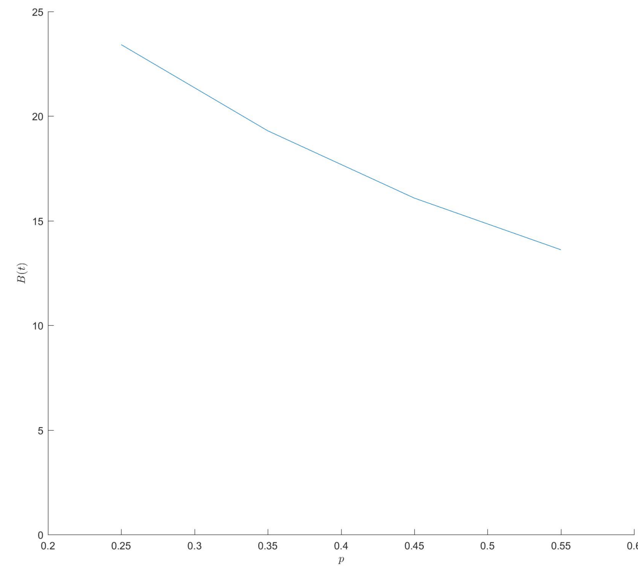

Figure 7: p

6.2 Ecological & Economic Balance Model

1. ϵ (not sensitive)

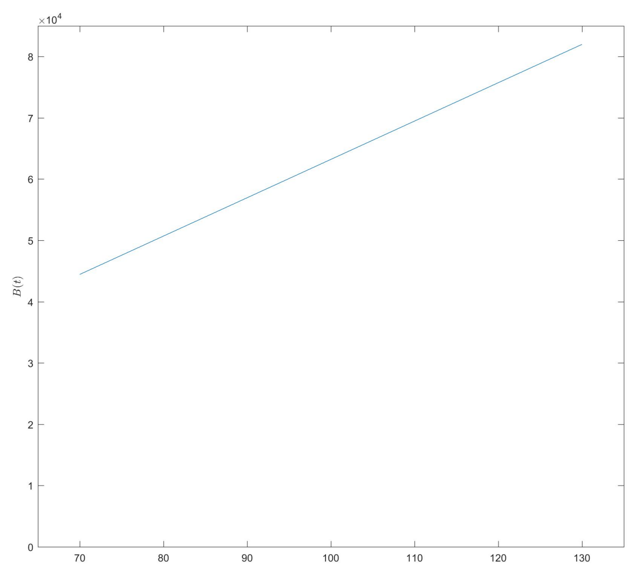

Figure 8: ϵ

2. λ (not sensitive)

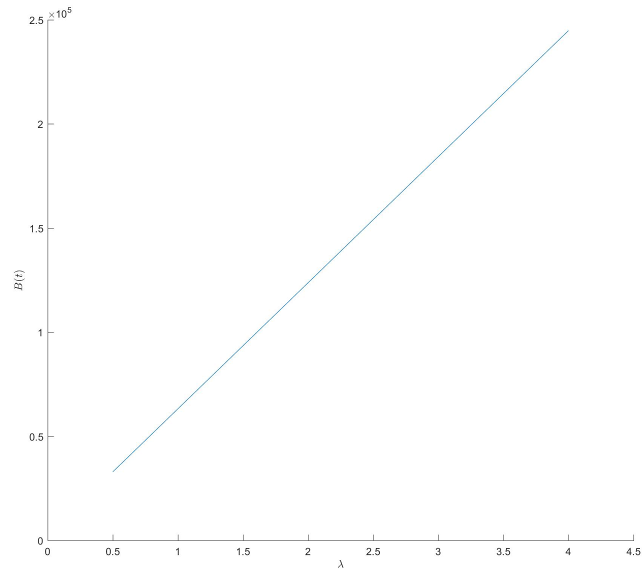

Figure 9: λ

3. Δt (not sensitive)

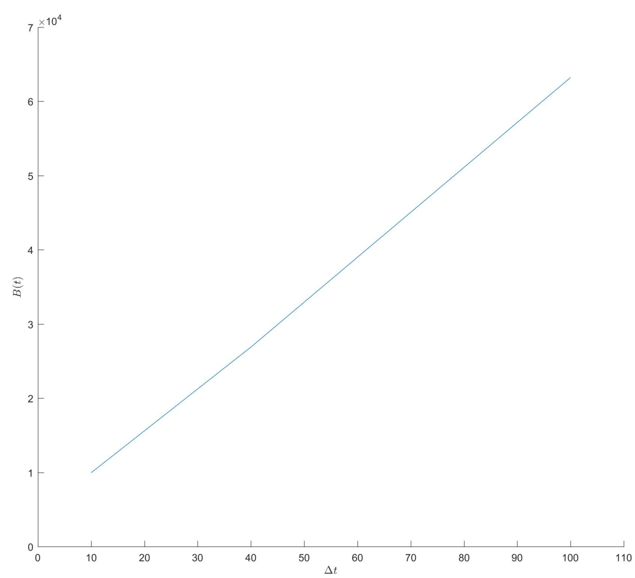

Figure 10: Δt

7 Strengths and Weaknesses

7.1 Strengths

1. **Our models are generally robust.**

   Most of our assumptions are reasonable and close to reality such as *Assumption* 1 & *Assumption* 4.

2. **Our quantification of ecological benefit is reasonable and viable.**

   We establish the relationship between ecological and economic benefit through carbon market platforms. In this way, the unit of the 2 benefits are unified, thus making their balance easier and more scientific.

7.2 Weaknesses

1. **The burden of parameter measurements is too heavy for forest management department.**

   Two essential parameters, λ and p, which depend on tree species, are hard to measure. Only controlling variables can realize its measurement, which is heavy work for forest management department.

2. **Our model is sometimes fragile.**

   Assumption 3 is not so close to reality. In fact, there often lives different kinds of trees in a continuous area. So it makes our model sometimes fragile.

Hello. We are ICM Team 2226737.

As the continuous burning of fossil fuels, the carbon dioxide content in the atmosphere is increasing, causing a global crisis. Measures like mechanical intervening and planting trees are becoming more and more popular. Recently we have conducted a research on the optimization of forest management plan. However its result conflicts with the public cognition that trees should always be protected and not cut down for other purposes. Both our models and our program results suggest a proper harvest plan rather than blind forest protection.

For a forest, it mainly has 2 goals — to sequester more carbon and to earn more money. Our first model only aims at the latter. For a tree, it will grow and grow after being planted until the day it is harvested. Then it will become a product, and the carbon it has sequestered during its lifetime still remains. When the product finally dies, it is burned and all element of carbon is turned into carbon dioxide, realizing the conservation of carbon. The death of previous products has already become beyond control now, so what we should focus on is how to maximize the carbon sequestration by modifying the forest management plan.

Just like human body, a tree has its life stages. When a tree lives beyond its peak productivity, its physical function begins to decline. When its ability to undergo photosynthesis drops to zero, it dies and it has no use to environmental protection. Obviously, at a tree's death, it should be harvested to clear up space for new saplings.

This is very obvious and reasonable. What if we harvest them earlier? We should compare the total amount of photosynthesis between different harvest time. The default is when a tree dies. For a short time after the harvest, the photosynthesis ability of the new sapling has not yet reached the otherwise surviving old one. But as time flows, the original one starts to get weaker while the sapling stronger. There must be a point. From that point on, the sapling outperforms the old tree. So, harvesting before death is a reasonable choice even for environmental protection.

Now we have proved that cutting down trees properly is reasonable. The task from now on is to determine the optimum harvest time. You can view our essay if you are curious about the further mechanism.

References

[1] Trading Economics. *EU Carbon Permits*. URL: https://tradingeconomics.com/commodity/carbon.

[2] R.A.Savidge S.H.Lamlom. "A reassessment of carbon content in wood: variation within and between 41 North American species". In: *Biomass and Bioenergy* (2003).

[3] the United Nations. *Forest Products 2019*.

A Source Code

A.1 Management Optimization Algorithm

```
#include<bits/stdc++.h>
#include<windows.h>
#include<sstream>
#define TRCNT 1000
#define PRMCNT 4
using namespace std;
int lambda,t;
double p,maxf,f,S,step,plant_den,minrng;
struct prm{
    double start,end,val;
    double maxval;
}param[PRMCNT];
struct tre{
    double birth;
    double x,y;
    double sigmaN(double t){
        return 50*lambda/t*(p/(t+p)+log(t+p)-log(p)-1);
    };
    bool inDst(){
        return x>=param[0].val && x<=param[2].val && y>=param[1].val && y<=param[3].val;
    }
}tree[TRCNT];
void cls(string s){
    string scrInit = "Harvest Plan Decision System\nBy MCM/ICM Team 2226737\n
        =========================================\n";
    system("cls");
    cout<<scrInit<<s<<endl;
    Sleep(500);
}
int main(){
    freopen("tree.dat","r",stdin);
```

```
freopen("tree.out","w",stdout);

cls("Reading␣parameters(lambda,␣p,␣t)...");
cin>>lambda>>p>>t;

cls("Reading␣scanning␣range␣and␣step:");
cin>>param[0].start>>param[0].end>>param[1].start>>param[1].end>>step>>minrng;
param[2].start=param[0].start,param[2].end=param[0].end;
param[3].start=param[1].start,param[3].end=param[1].end;

int tmp;
cin>>tmp;
plant_den=tmp/(param[1].end−param[1].start)/(param[0].end−param[0].end);
for(int i=0;i<tmp;i++)cin>>tree[i].birth>>tree[i].x>>tree[i].y;

cls("Calculating...");
for(param[0].val=param[0].start;param[0].val<param[0].end;param[0].val+=step){
    for(param[1].val=param[1].start;param[1].val<param[1].end;param[1].val+=step){
        for(param[2].val=param[0].val+step+minrng;param[2].val<param[2].end;param[2].val
            +=step){
            for(param[3].val=param[1].val+step+minrng;param[3].val<param[3].end;param
                [3].val+=step){
                f=0;
                int cnt=0;
                for(int i=0;i<tmp;i++){
                    if(tree[i].inDst()){
                        cnt++;
                        f+=pow(tree[i].sigmaN(−tree[i].birth)−tree[i].sigmaN(1),2);
                    }
                }
                f=sqrt(f/cnt);
                if(f>maxf){
                    maxf=f;
                    for(int j=0;j<PRMCNT;j++)param[j].maxval=param[j].val;
                }
            }
        }
    }
}

cout<<"Finished.\nOptimal␣Harvest␣Area:"<<endl;
cout<<"x:␣From␣"<<param[0].maxval<<"␣to␣"<<param[2].maxval<<endl;
cout<<"y:␣From␣"<<param[1].maxval<<"␣to␣"<<param[3].maxval<<endl;
cout<<"Thanks␣for␣using."<<endl;
cout<<"Quitting..."<<endl;
```

```
    Sleep(1000);
    system("pause");
    return 0;
}
```

A.2 Ecological & Economic Balance Algorithm

```
#include<bits/stdc++.h>
#include<windows.h>
#include<sstream>
#define PIE 3.1415926
#define TRCNT 1000
#define PRMCNT 4
using namespace std;
int t;
double epsilon,lambda,deltat,p,step,minrng,maxf;
struct prm{
    double start,end,val;
    double maxval;
}param[PRMCNT];
struct tre{
    double birth;
    double x,y;
    double sigma(double t){
        return p/(t+p)+log(t+p);
    };
    bool inDst(){
        return x>=param[0].val && x<=param[2].val && y>=param[1].val && y<=param[3].val;
    }
}tree[TRCNT];
void cls(string s){
    string scrInit = "[Advanced]␣Harvest␣Plan␣Decision␣System\nBy␣MCM/ICM␣Team␣2226737\
        n=========================================\n";
    system("cls");
    cout<<scrInit<<s<<endl;
    Sleep(500);
}
int main(){
    freopen("ad_tree.dat","r",stdin);

    cls("Reading␣parameters(epsilon,␣lambda,␣deltat,␣p)...");
    cin>>epsilon>>lambda>>deltat>>p;

    cls("Reading␣scanning␣range␣and␣step:");
```

```
    cin>>param[0].start>>param[0].end>>param[1].start>>param[1].end>>step>>minrng;
    param[2].start=param[0].start,param[2].end=param[0].end;
    param[3].start=param[1].start,param[3].end=param[1].end;

    int tmp;
    cin>>tmp;
    for(int i=0;i<tmp;i++)cin>>tree[i].birth>>tree[i].x>>tree[i].y;

    cls("Calculating...");
    for(param[0].val=param[0].start;param[0].val<param[0].end;param[0].val+=step){
        for(param[1].val=param[1].start;param[1].val<param[1].end;param[1].val+=step){
            for(param[2].val=param[0].val+step+minrng;param[2].val<param[2].end;param[2].val
                +=step){
                for(param[3].val=param[1].val+step+minrng;param[3].val<param[3].end;param
                    [3].val+=step){
                    double f=0;
                    int cnt=0;
                    for(int i=0;i<tmp;i++){
                        if(tree[i].inDst()){
                            cnt++;
                            f+=tree[i].sigma(-tree[i].birth);
                            f*=epsilon*lambda*deltat/(2.1625816*p);
                            f-=epsilon*cnt*(log(p)+1);
                            f+=PIE*6.4*cnt;
                        }
                    }
                    if(f>maxf){
                        maxf=f;
                        for(int j=0;j<PRMCNT;j++)param[j].maxval=param[j].val;
                    }
                }
            }
        }
    }

    cout<<"Finished.\nOptimal Harvest Area:"<<endl;
    cout<<"x: From "<<param[0].maxval<<" to "<<param[2].maxval<<endl;
    cout<<"y: From "<<param[1].maxval<<" to "<<param[3].maxval<<endl;
    cout<<"Thanks for using."<<endl;
    cout<<"Quitting..."<<endl;
    Sleep(1000);
    system("pause");
    return 0;
}
```

B User Manual

General

- If the forest contains multiple tree species, separate them so that there is only one species in any section.
- λ indicates a tree species' maximum ability for photosynthesis
- p indicates the peak productivity age for a tree species (unit: one average lifespan of the tree in the column)

Input

- The first line of the input should contain λ, p.
- The second line contains 6 numbers: start of x, end of x, start of y, end of y, scan step length and the minimum harvest area's side length to be accepted. The 6 numbers should have the same unit (e.g. 10m). Scan step length is recommended to be no smaller than 0.1% of either x length or y length.
- The next line should contain a number indicating the number of trees.
- On each line of the following lines, there should be the age, x coord and y coord of a tree. The numbers should be separated by only one space.

File

- The inputs mentioned above should be stored into a file named "tree.dat". To do this, you can first create a .txt file and then change the file type to .dat. Ignore any warnings.

Usage

- The tree.dat file should be placed in the same path as the decision.exe. Double-click the .exe and wait for results. The results' unit is the unit determined during inputting.