Problem Chosen	2023 MCM/ICM Summary Sheet	Team Control Number
B		**2312480**

Manage Maasai Mara

Summary

The Maasai Mara is a national game preserve with one of the largest animal population in the world. Although the Maasai Mara plays an essential role in the local environment, it can also lead to unneglectable conflicts between natural resources and human interests. Hence, this report aims to find out a methodology to rank and thus figure out an optimal policy or management strategy.

The policies will be made to restrict or legalize hunting and land exploitation, which are the most essential parts in the Maasai Mara living.

In order to determine the hunting policy, we develop the **hunting model**. We first assign weight to different animal species according to their endangerment assessment by introducing the Red List Index. After that, we deduce a formula to derive the specific **Hunting-Negative-Impacts Model**. In this submodel, the ratio of the number of animals of a species to the total population, the endangerment scale constant and the maximal hunting proportion to the species population are taken into account. As for the second submodel, we consider the economic profit of hunting. Assuming that every hunted animal contributes profit to the local people's income, we develop the Hunting-Economics-Profit Model considering both the profit and the initial population of each animal species.

For **land exploitation model** built to determine land allocation strategy, we first estimate the **habitat loss impact** on the animal population. The result shows that the death rate of an animal species increase by 1.04% corresponding to 1% degradation of the animal habitat. Using this constant as well as the endangerment scale obtained in the hunting model, we establish a submodel of the **space-loss harm index**. Meanwhile, we evaluate the productivity of a certain area of exploited land by defining a weighted average for the economic value of tourism, agriculture and husbandry, which is the three major income sources in Kenya. Specifically, we model the **demand curve of the ticket market** and is able to obtain the dynamic profit in tourism. We then use the average productivity of land utilizing by local people to calculate the other revenue. Adding them together and substract them by the cost, we successfully model the **economic gain index in land exploitation**.

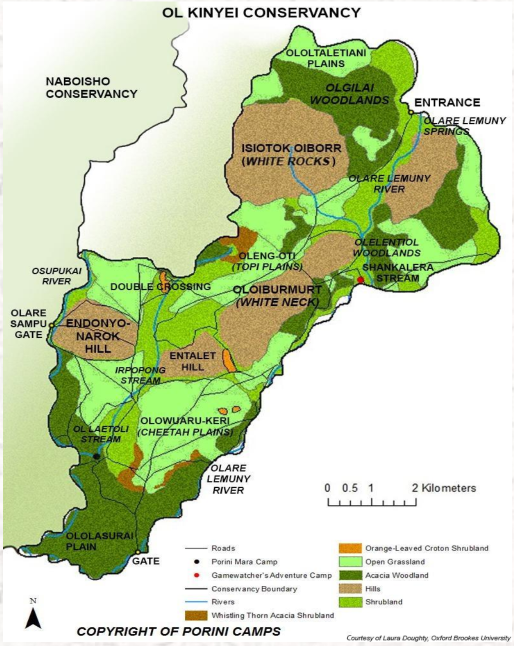
To sum the submodels above together into a well-rounded methodology, we combine the four submodels into one equation, in which the relationship of scaled economics profit and the negative ecological impacts are formulated. We also use simulate annealing to obtain the value of each variables while achieving the optimal outcome of the formula. **the optimization model** allows us to determine and recommend specific policy system. Lastly, we introduce **logistic model** to model animal population growth and make short and long-term prediction of the outcomes of our policies.

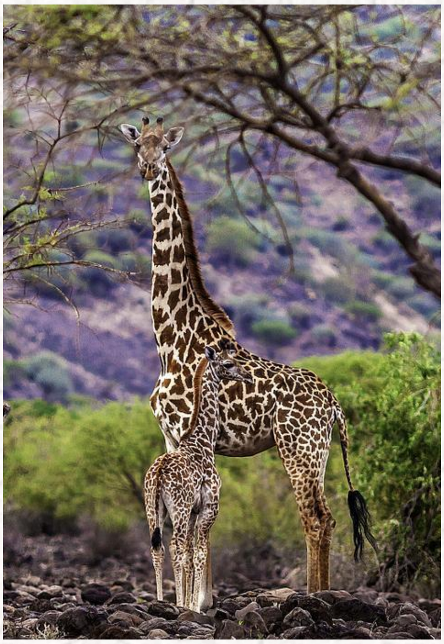
Keywords: Positive and Negative Impact model, Optimization Model, simulate annealing

Policy Recommendation Report: Sustainable Development Plan for Maasai Mara Wildlife Preserve

1 Introduction

Maasai Mara national preserve, known for its huge wildlife population, shoulders the tast of not only protecting the precious wildlife and the other natural resources, but also the responsibility to balance the welfare of animals and interests people near or in the game preserve area. Indeed, according to our deep research and analysis into the ecological and economic circumstance in Maasai Mara, a new policy system should be made and is here proposed to develop Maasai Mara into a sustainable game preserve in the 21st century.





the landscape of Masai Mara Conservancy

2 Research Overview

2.1 The Environmental and Economics Background

The Maasai Mara game preserve has an area of 1510 km^2 . The distribution and basic condition of some species are listed below:

Species	Population	Endangerment	Natural Growth Rate
lion	875	vulnerable	0.707
zebra	200,000	near threatened/least concerned	0.0200
elephant	2500	critically endangered	0.0209

Base on the mathematical models we made, hunting and land exploitation are two main factors that can contribute to sustainable development. The essential influence factors of which are listed as follow:

-Animal Scarcity
-Animal Security
-Species Proportion
-Habitat Loss

2.2 The Economics Scaling and Value in Maasai Mara

The local people and the government's income source in Maasai Mara are distributed intensively in the following areas:

-Tourism, specifically the ticket profit of the national park
-Agriculture, cropping and farming
-Pastoralism, graving in or near the preserved area

3 Discussion of Research Findings

By constructing mathematical models which reflect relationship between the economical and environmental variables, we find out the balanced hunting proportion and the optimal land exploitation percentage:

Optimal Total Land Exploit Percentage(Agriculture+Pastoralism+Tourism) (%)	25.271
Optimal Park Exploit Percentage(%)	2.911
Optimal Total Land Exploit Area(km^2)	382.03
Optimal Park Exploit Area(km^2)	43.79

Table 1: Balanced Land Exploitation

Species	Optimal Hunted Population Percentage(%)	Optimal Annual Hunted Population
Lion	0.155	1
Zebra	8.535	1,7070
Elephant	1.080	27

Table 2: Balanced Hunting Proportion

4 Conclusion and Recommendation

In conclusion, the interaction between animals and people is inevitable in Maasai Mara. A sustainable policy system should minimize the human impacts on the ecology while balancing the interest of people.

Base on the research and the mathematical model analysis, we would like to give following recommendation:

1. Legalize while strictly regulate the bushmeat market, restrict the hunting quantity in the optimal hunted percentage range
2. Restrict the land exploitation. The whole area of exploited land in Maasai Mara should not be more than 382.03 km^2, while the park exploit area for tourist accomodation and infrastructure is well managed in the optimal park exploit percentage range.

Contents

1 Introduction

1.1 Background

The Maasai Mara, one of the largest Kenya wildlife preserves known for its great populations of wildlife, was established in 1961 with an area of 1,510 km^2. Wildlife including Big Nine African animals and over 400 bird species thrives in this area. At the same time, human population also keeps increasing. While the activities of the Maasai Mara people and the tourists are believed to cause affects on animals and environment, distributing restricted source of natural resources, mitigating lost opportunities of local people and negative impacts on animals is a challenging problem. A new system of policies and management strategies of the Maasai Mara is required for balancing and predicting the relationship between people, wildlife and other natural resources.

1.2 Restatement of the Problem

This paper aims to recommend policies and determine ways to manage the resources of the Maasai Mara Game Preserve via proper models. We are expected to solve the following problems:

- **Problem 1**: We are asked to recommend specific policies and management strategies for different areas within the Maasai Mara by considering the the loss impacts on local people and negative interactions between animals and people.
- **Problem 2**: Develop a model to evaluate the effectiveness of the policies and strategies, include both negative impacts on animals and economical impacts on the local area and people.
- **Problem 3**: Predict the long-term outcomes of the policies, analyze the certainties and impacts. Apply your model to other wildlife management areas.
- **Non-technical Report**: Provide a two-page non-technical report for the Kenyan Tourism and Wildlife Committee discussing your proposed plan and its value for the preserve.

2 Assumptions and Justification

- **The animal population is evenly distributed** Justification: the density of the animals can alter due to different factors. In this paper, we assume that the animals are fairly distributed for simplicity.
- **The annual implementation cost of the park infrastructure remains the same**. Justification: the annual fluctuation of the implementation cost can be negligible comparing to the ticket and accommodation revenue value.
- **Assume that every hunted animal contributes to the bushmeat profit**. Justification: Some of the animals are hunted for other usages. However, we neglect them in our paper for simplicity, since bushmeat is the most major reason for hunting in Kenya.

3 Notations

in which the subscript "$_i$" is the identical number of animal species, i=1, 2, 3

Symbol	Description	Unit
K_i	the ratio of the number of animals of a species to the total population	$\%$
K_E	total exploitation percentage of land	$\%$
K_T	exploited area for tourism as percentage of the total exploited area	$\%$
H_i	the number of animals of a species that can be hunted as a percentage of its population in the give	$\%$
P_i	Bushmeat price	$\$$
n_i	population number	N/A
ΔDR	death rate difference in certain time span	N/A
S	total area of Maasai Mara	km^2

4 Model Overview

In order to analyze the policies, we set up negative impact model and positive interest model for hunting and land exploitation, which are listed below:

Hunting Policy:
In order to balance the interests of people by the area, we establish the **Hunting Negative Impact Model** We assign weights on the discussed animal species based on how endangered they are. The animal scarcity and species population proportion are also taken into account. By inserting the initial animal population into the model, we can calculate the hunting harm index of different animal species.

After that, we introduce the **Hunting Economics Profit model** by considering both the hunting profit and the maximum hunting proportoin for each species. With the consideration in the economics value of bushmeat and proper number of the animals hunted, the hunting gain-index is modeled.

Land Exploit Policy:
Land Exploited Negative Impacts Model is constructed by quantifying the impact on the wildlife when area of the game reserve is exploited. Habitat loss and animal scarcity are factors considered in this model. By evaluating the urgency of protection for different species and the possible death rate, we are able to model the harm-index of land exploitation by certain percentage.

Considering that land exploitation in a game reserve can also bring economic income, we then create an **Land Exploit Economics Profit Model** to estimate the total profit of land exploitation by utilizing submodels to estimate the possible ticket profit of the tourism as well as the agricultural and animal husbandry profit gained by local people.

Optimization Model:
By using **simulate annealing** to analyze the variables obtained above, we are able to gain the value of the variables when the result is maximized, which indicates that the interaction

between animals and people are best resolved and the balance between natural resources and human interests is optimal. We, then, determine the specific policies using these data. We also develop **the balance index** so that certain policies can be ranked and evaluated.

Long-term Model:
To develop a long term model about the long term economic and ecologic the policy may bring to local people, we first build an **animal population model** based on logistic model. After observing a positive relationship between the animal population and the economic profit, we also deduce an **alternative policy making approach** that uses "not to diminish the population of animals" as a premise.

5 Problem 1 and 2: Determine Policies and Strategies

Problem 1 requires us to specific policies and management for different areas in order to protect wildlife and other natural resources while also balancing the interests of the local people. The policies should minimize the negative interactions and local people's loss opportunities. Problem 2 requires us to determine a methodology to rank the policies while taking economics impacts into consideration.

In this section, for every policy, we develop two models corresponding to the evaluations of the negative impacts on animals and economics profit to the local people respectively. We combine the four submodels (two policies, each has a negative impacts model and an economics profit model) into one formula by subtracting the scaled economics profit using the scaled negative impacts, and use simulate annealing to gain the value of the variables when the result of the new formula is maximized. Knowing these values, we would be able to determine specific policies. We plug in these resulting values into the land policy and hunting policy's Balance Indexes and compare them in order to rank the outcomes.

5.1 Policy 1: Legalize While Strictly Regulate the Bushmeat Market

We conducted research on the economy of the Maasai Mara and nearby areas, and discovered that bushmeat proaching is a significant component of the wildlife's economics value, far in

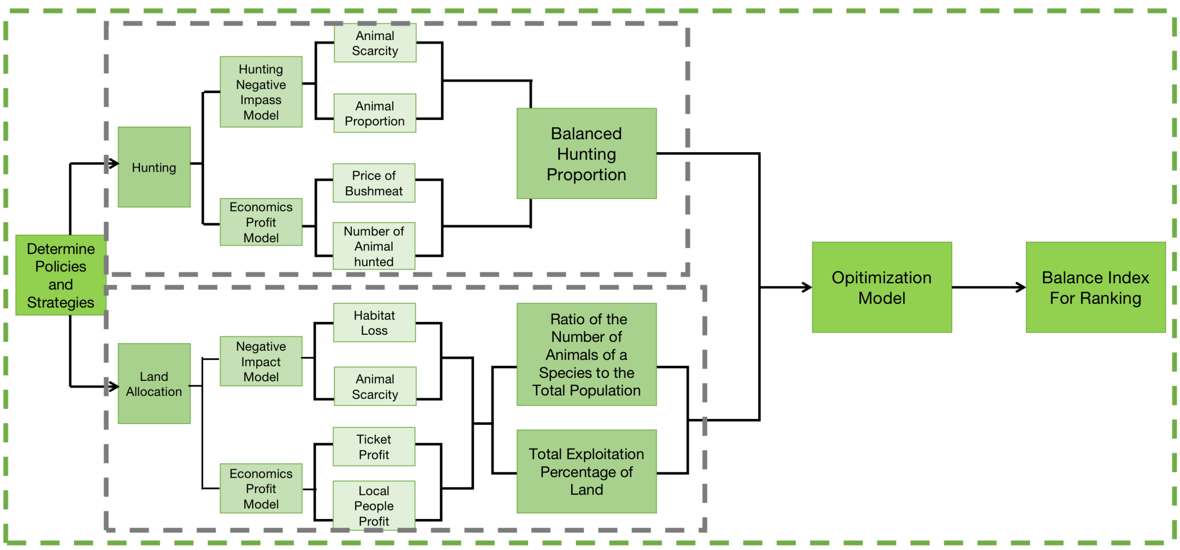


Figure 1: Model Overview Mindmap

excess of legalized hunting, tourism or trophy values[1].

Bushmeat proaching directly contradicts wildlife conservation objectives, while the current laws seemed to have little effects on forbidding it. A survey based on Kenyan identified that 79.9% of the community consumed bushmeat, with 67% claiming that bushmeat was their most important source of protein[1]. Besides being the source of protein, killing wildlife to demonstrate strengths has also been an important ritual of the local people. Hence, it seems impossible and unrealistic to fully ban bushmeat trade. Throughout Kenya, there has been "a reduced poaching catch per effort, increased trade supply, increased use of sophisticated weapons, off-take from PAs, negligible law enforcement and destruction of traditional hunting seasons"[1]. At the same time, since bushmeat trade is illegal in Kenya, the government will not regulate the safety and health index of bushmeat in the market, further leading to health issues of the local people.

Legalizing while strictly regulating the bushmeat market seems to be a good strategy to benefit local economy, and give local people more rights of gaining natural resources due to the fact that bushmeat is an inseparable source of their diet. This policy also takes humanistic care of the tradition of local people and enables the government to regulate bushmeat quality. The only thing is that we have to balance the economy interests and the negative impacts on animals. As a result, we developed **the Hunting Model** to determine the specific policy and management strategies.

5.1.1 The Hunting Model

We develop this model to obtain H_i (the number of animals of a species that can be hunted as a percentage of its population in the given area). As we discussed in the model overview part, we use lions, zebras, and elephants as our animal representatives, which in turn corresponding to 1, 2, and 3.

In order to obtain the result that can best balance the negative impacts on wildlife and the economics profit created by this policy, we develop the models for negative impacts (NI_{H_i}) and Economics profit ($Econ_{H_i}$) separately.

5.1.2 Hunting-Negative-Impacts Model

To begin with, since different species have relatively different importance due to their differences in scarcity, the negative impact of killing each different animal is naturally different. Based on the Red List Index (RLI) of species survival[8], we use a scale of 0 to 7 to describe how endangered the three species of animals are:

Table 1: Animal Endangerment Assessment Scale

Endangerment	protect urgency Constant	Species
$notevaluated$	0	/
$datadeficient$	1	/
$leastcocern$	2	Zebra
$nearthreatened$	3	Zebra
$vulnerable$	4	African Lions
$endangered$	5	/
$criticallyendangered$	6	African Elephant
$extinctinthewild$	7	/

Note that the zebra's protect urgency constant here is taken as 2.5 due to its instable endangerment condition in dry and wet seasons.

We use SC_i to represent this index, and now we start to model the negative impacts on animals:

$$NI(H_i) = \sum_{1}^{3} K_i \times SC_i \times H_i, i = 1, 2, 3 \tag{1}$$

in which K_i is the percentage of the population (n) in a certain animal species out of the total animal population in the area. We obtain the value of K_i by conducting research on the given area.

It's important to mention that the result of **the Hunting-Negative-Impacts-Model** is an index without any unit because negative impacts are hard to express in a single unit. However, for **the Hunting-Economics-Profit Model** which will be explained in the next subsection, the result is in dollar terms, and we can calculate the exact economic profit.

5.1.3 Hunting-Economics-Profit Model

Our formula for the hunting economics profit is:

$$Econ(H_i) = \sum_{1}^{3} \times P_i \times H_i \times n_i, i = 1, 2, 3 \tag{2}$$

It's simply the product of the price of the animal and the number of animals local people hunt. P_i is the price of the certain species of animals, H_i is the number of animals of a species that can be hunted as a percentage of its population in the given area, and n_i is the population of the species in the given area. Note that we do not take the cost of hunting into consideration here because it's difficult to obtain the precise costs the local people have to pay for hunting, and we assume it to be negligible.

We obtain the value of P_i and n_i by conducting research on the given area.

Now we stop here and wait until we develop **the Land-Exploitation-Negative-Impacts Model** and **the Land-Exploitation-Economics-Profit Model**. Then we combine all the four models into one formula and then we will use simulate annealing to find the results when the result of formula is maximized. The reason we are putting them altogether is because some variables are shared by the models and some variables of different models might be interrelated.

5.2 Policy 2: Land Exploitation Policy

The construction of wildlife preserves, such as Maasai Mara, can attract hundreds of thousands of tourists every year, earning incredible profit, but it also restricts the interests and income sources of local people as well as the habitats of wildlife.

Many residents in the Maasai Mara depend on agriculture and animal husbandry for living. These two ways play indispensable roles on the rural economy. The study of economic situation in Kenya shows that the 27% of total Gross Domestic Product(GDP) is contributed directly by agriculture[5], and Kenya's husbandry sector has an economic worth of US1.13 billion with the livestock sector and non-livestock sector accounting for 92% (US$1.04 billion) and 8%

(US$0.0903 billion), respectively[6]. This embodies the necessity of land usage for cropping and grazing in Maasai Mara. However, the overdevelopment of land has been proven to cause land degradation and animal habitat loss. While the land under farming in Maasai Mara District grows from 10000 ha. to 110000 ha., the forest area shows an 60% decrease from 1975 to 2000[1].

At the same time, some of the land needs to be exploited for tourism, which also takes away some parts of land from wildlife as well as local people.

Considering both the negative influence and the economic value land exploitation brings, **the Land Exploitation Model** is developed to determine an optimal rate of land use in order to protect the local ecosystem as well as the income source for the local residents in the Maasai Mara and balance the profit of the Maasai Mara National Preserve earned from tourism.

5.2.1 The Land Exploitation Model

We develop this model to obtain K_E and K_T. It's important to recognize the difference between these two variables. K_E is the total exploitation percentage, the area we exploited as a percentage of the total given area. It contains both the area exploited for local people and the area exploited for tourism. K_T is the exploited area we use for tourism as a percentage of the total exploited area.

In order to obtain the result that can best balance the negative impacts on wildlife and the economics profit created by this policy, we develop the models for negative impacts $NI(K_E)$ and Economics profit $Econ(K_E, K_T)$ separately.

5.2.2 The Environmental Land Exploitation Model

First of all, we are required to define the relationship between animals and land exploitation. Inspired by this, we introduce the concept of **the habitat loss impact LI** in Maasai Mara by defining it as the the rate of animal population declination with the rate of land degradation in a certain time quantum. We assume here that the habitat loss impact for every animal species is equal, as different animal responses to the land area change is indistinguishable and negligible. We can obtain a constant of land exploitation impact by the following model:

$$LI = \frac{\Delta DR}{HL} \tag{3}$$

Then, we determine the parameters in this model, namely the population difference ratio and the habitat loss ratio in a certain time span. LI is the relationship between the death rate increase and the habitat loss in a certain time span and area.

We consider zebra as the representative animal species as they are most widely distributed in Maasai Mara, so that a constant of LI with higher universality will be obtained. San Diego Zoo Wildlife Alliance has listed out the historical global population of Grevy's Zebra, namely 15,000 in 1960s and 2206 total population in year 2008[7]. The habitat has shriunken by 77.26%[8], according to a map diagram which shows the historical range and current range of Grevy's Zebra population. Putting the above value of parameters in to the equation (3), we can get the data listed in Table 2.

The result shows that the death rate of an animal species increases by 1.04% corresponding to 1% degradation of the animal habitat:

Table 2: Calculating Results-Land Exploitation Impact

Variables	Values	Unit
ΔDR	85.3	$\%$
HL	77.26	$\%$
LI	1.04	$\%$

$$LI = 0.0104 \tag{4}$$

Finally, we are able to provide the whole **Land-Exploitation-Negative-Impacts Model**. We still consider in this model the index of species endangerment (SC_i), the habitat loss impact (HI), the total exploitation percentage of land in the given area (K_E), and the percentage of the population in a certain animal species out of the total animal population in the area (K_i).

$$NI(K_E) = K_E \times (1 + LI) \times \sum_{1}^{3}(K_i \times SC_i), i = 1, 2, 3 \tag{5}$$

5.2.3 The Land-Exploitation-Economics-Profit Model

In this model, we consider multiple factors as their are many ways using the land to earn profit. First we divide the profit into two categories: the profit earned by local people through agriculture and animal husbandry and that earned by the National Preserve from the tourists.

- **Calculating profit earned from the tourists**

  In this submodel, we did not take the profit earned from accommodation and other aspects besides ticket sells into consideration because it varies a lot according to different visitors and the statistics of the cost for these service is very limited.

  We first have to calculate the ticket sell revenue. It's very easy to obtain the formula, which is the quantity of the tickets sold $\times$ the prize of the tickets.

$$T_{ck}R = Q \times P \tag{6}$$

  However, most of the national preserves would apply price discrimination to maximize its revenue by charging different prizes to domestic citizen and foreign visitors. We simulate price discrimination based on two demand curves of Lake Nakuru National Park's ticket market in a year[3].

$$\begin{cases} P_d = 0.008 \cdot (-2.63Q_d + 423.3 \cdot 1000) \\ P_f = 0.008 \cdot (0.16Q_f + 18.5 \cdot 1000) \end{cases} \tag{7}$$

  The first formula is the formula for domestic citizens' ticket prize, and the second formula is the formula for foreign visitors' ticket prize.

  While conducting research, we discover that when the animal density is increased by 1%, the visitors density is increased by 7000 (people per square kilometer).

We have our modified animal density(AD'):

$$AD' = \sum_{1}^{3} \times n/S \times [1 - K_E \times (1 + HL) - H_i + R_i]K_i, i = 1, 2, 3 \tag{8}$$

, where n is the total number of animals, S is the total area.

$$\Delta Q = 7000 \cdot (AD' - AD) \tag{9}$$

We further improve our model by considering the demand shift.

$$\begin{cases} P_d = 0.008 \cdot [-2.63(Q_d - \Delta Q) + 423.3 \cdot 1000] \\ P_f = 0.008 \cdot [0.16(Q_f - \Delta Q) + 18.5 \cdot 1000] \end{cases} \tag{10}$$

We also develop a model to for the total quantity of tourists in a year(Q).

We discover that there is a linear relationship between the number of visitors to a park and the density of animals in the park. We collect ten national wildlife preserves' statistics of animal density and tourist numbers in a year and use linear regression to gain the equation:

$$Q = AD \cdot 2037.7 + 12292.2 \tag{11}$$

, where AD is the animal density of the national park.

In order to calculate the quantity of domestic and foreign visitors, we conduct research on the percentage of foreign tourists and domestic tourists respectively.

$$\begin{cases} Q_d = Q \cdot K_d \\ Q_f = Q \cdot k_f \end{cases} \tag{12}$$

Finally, we obtain the formula for ticket revenue.

$$T_{ck}R = Q_d \cdot P_d + Q_f \cdot P_f \tag{13}$$

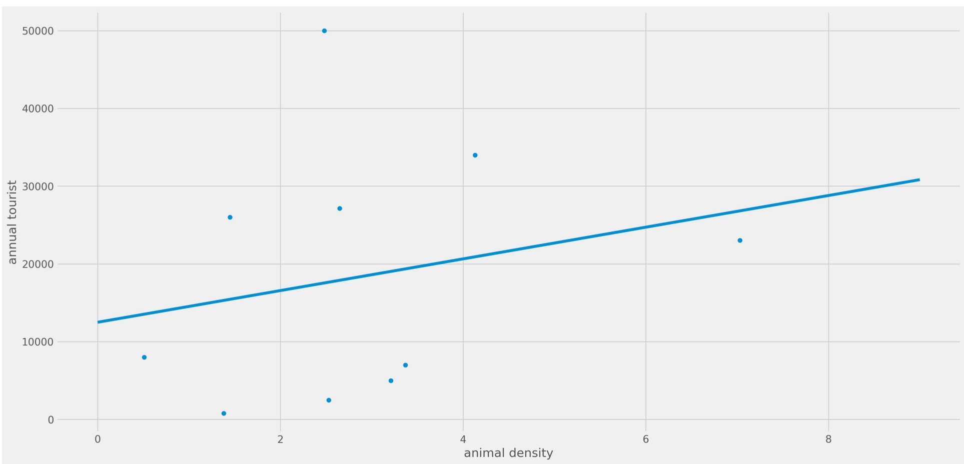


Figure 2: Linear relationship between animal density and annual tourists

Now we have to calculate the cost of holding the national preserve. We mainly consider two costs: the total tourists cost and the total implementation cost. The total tourists cost(TTC) is the cost of providing service to the tourists, and the total implementation cost(TIC) is the cost of maintaining unexploited area.

$$TTC = ATC \cdot Q \tag{14}$$

$$TIC = AIC \cdot (S - S_E) = AIC \cdot (S - S \cdot k_E) \tag{15}$$

, where S is the total area and S_E is the total exploited area. ATC is the average cost to service a person, we conducted research and calculated it to be around 5.5 dollar/person[3]. AIC is the average cost to maintain one square kilometer of unexploited land, which is 565 dollar per square kilometer[4].

- **Calculating profit earned by local people** As we stated before, the profit earned by local people can be mainly attributed to animal husbandry and agriculture. We collected data and calculated the average land productivity by using their GDP proportions. The resulting average land productivity (APR) is 83384 dollar per square kilometer:

$$LR = APR \cdot S_L = 83384 \cdot S_L = 83384 \cdot S_E \cdot (1 - K_T) \tag{16}$$

Note that we ignore the local people's cost since it's very difficult to obtain the statistics, and it is not deeply related to policy decisions. The major goal of this model is to minimize their opportunity loss of using natural resources.

After taking multiple factors into consideration, we can finally obtain our final **Land-Exploitation-Economics-Profit Model**:

$$Econ(K_E, K_T) = LR + T_{ck}R - TTC - TIC \tag{17}$$

5.2.4 Calculation and Results

We are required to balance the negative impact on animals and economics prodfit, and we have already built the models for both of them. Now we combine them together and use simulate annealing to find the values of H_i, K_E, and K_T when we maximize result of the combined formula.

This is our optimization model:

$$Max\ [Econ'(H_i) + Econ'(K_E, K_T) - NI'(H_i) - NI'(K_E)], \text{ i=1, 2, 3}$$

$$S.t. = \begin{cases} 0 \le H_1, H_2, H_3, K_E, K_T \le 1 \\ K_E \times K_T \times ExploitedTourismRatio + K_E \times (1 - K_T) > 1 \end{cases} \tag{18}$$

in which

$$Econ'(H_i) = \frac{Econ(Hi) - econ_H AVG}{econ_H STD}, i = 1, 2, 3 \tag{19}$$

$$Econ'(K_E, K_T) = \frac{Econ(K_E, K_T) - econ_L AVG}{econ_L STD}, i = 1, 2, 3 \tag{20}$$

$$NI'(H_i) = \frac{NI(H_i) - NI_H AVG}{NI_H STD}, i = 1, 2, 3 \tag{21}$$

$$NI'(K_E) = \frac{NI(K_E) - NI_L AVG}{NI_L STD}, i = 1, 2, 3 \tag{22}$$

There exists **two main constraints** for the variables as shown in s.t.:

Firstly, because all the variables represent a percentage, it must be between 0 and 1. Secondly, because the exploited area only makes up for 1.5 percents of the area of the whole park, and we want the whole park to be within the total area.

The $'$ sign
The $'$ sign is used to signify a scaled and nondimensionalized data.

The Algorithm
To solve this discrete optimization problem, we adopt simulated annealing algorithm. The algorithm mainly consists of 3 part:

1) The disturbance of the data.

During each iteration, the current group of solutions will be shifted randomly to other values with an amplitude related to current temperature. The lower the current temperature is, the smaller the disturbance will be. Thus, the system will approach to reach a stable solution at last.

2) The acceptance of the solution.

If the solution is greater than the previous one, accept it. Otherwise, the algorithm will accept the solution at a probability of:

$$e^{\frac{-|f(x_{new}) - f(x_{old})|}{T}} \tag{23}$$

where T denotes the current temperature. Here, as T becomes smaller, the probability to accept a worse solution will be lowered, which also suggests the system to approach a rather stable state.

3) The update of temperature

After each set of iteration, the T value will be lowered. As T becomes less than a critical value, the algorithm terminates.

5.2.5 Results and Analysis

To test the model, we choose two different areas in Maasai Mara.

The first area is Olare Motorogi Conservancy. Below is the basic information of this conservancy: (Table.3)

Below is a graph that shows the best solution found versus number of iterations. (fig.3)

Table 3: Olare Motorogi Conservancy Basic Information

Total Area	Initial Lion	Initial Elephant	Initial Zebra
136	100	150	180

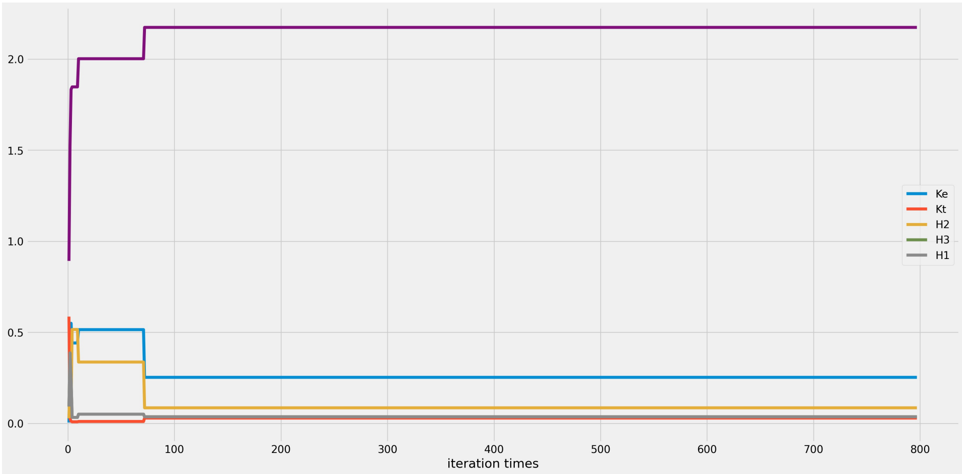


Figure 3: Simulated Annealing Algorithm for Best Solution in Olare Motorogi Conservancy

The second area we choose is Mara North Conservancy. Below is the basic information of this conservancy: (Table.5)

Below is a graph that shows the best solution found versus number of iterations. (Fig.4)

5.2.6 Methodology for Evaluating and Ranking the Outcomes of Different Policies

In order to rank the effectiveness of the two policies, we introduce the balance index. After we obtain the value of $Econ'(H_i)$,$Econ'(K_E, K_T)$, $NI'(H_i)$, $NI'(K_E)$, The Balance Index of Hunting Policy(BIH) is:

$$BIH = Econ'(H_i) - NI'(H_i) \tag{24}$$

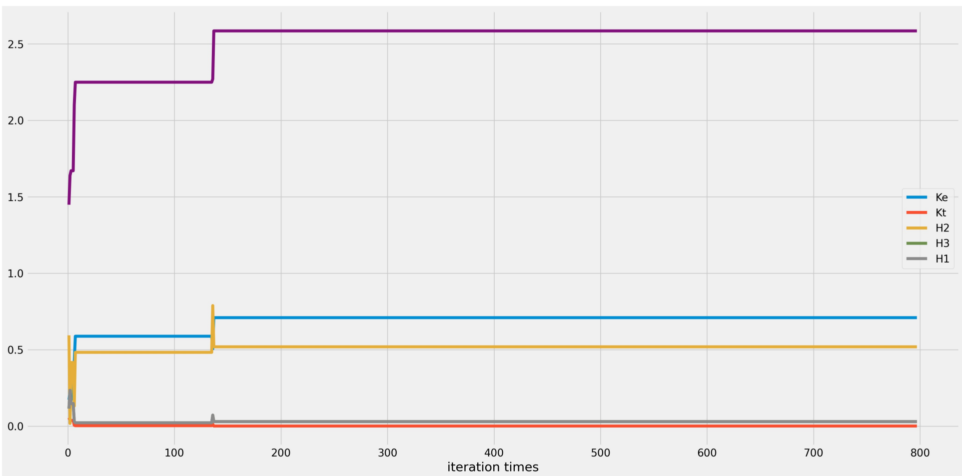


Figure 4: Simulated Annealing Algorithm for Best Solution in Mara North Conservancy

Table 4: Calculated Policy for Olare Motorogi Conservancy

Symbol	Percentage
K'_E	0.2527
K'_T	0.0291
H'_1	0.0611
H'_2	0.0853
H'_3	0.0361

Table 5: Mara North Conservancy Basic Information

Total Area	Initial Lion	Initial Elephant	Initial Zebra
280	80	200	30

Same, the Balance Index of Land Policy(BIL) is:

$$BIL = Econ'(K_E, K_T) - NI'(K_E) \tag{25}$$

And then we just need to simply compare BIH and BIL to see which policy is more balanced more effective.

6 Problem 3: Analyze Long-term Outcomes

6.1 Long Term Population Model

Firstly we notice that, the most significant difference between long term and short term outcome is that in long term, the population of animals varies. This may directly lead to the change in both the hunting income (since it is dependent to the number of animals), and the national park ticket income (since it is dependent to the density of the animal. Thus, the first step to analyze long term outcomes of the population is to build a long term population model. We base our population model on logistic model, which states that:

$$\frac{dp}{dt} = r(1 - \frac{p}{m})p \tag{26}$$

where: p denotes the population of the animal, r is the natural change rate of the animal, and m is the maximum number of animals that the environment can accommodate.

However, this original model does not account for the extra death rate caused by policy allowance hunting, and since the policy only stipulates a percentage, it will not be influenced by the term $(1 - \frac{p}{m})$. Therefore, the modified population model shall be:

$$\frac{dp}{dt} = r(1 - \frac{p}{m})p - H_i p \tag{27}$$

It is hard to solve this differential equation, so we transform it into a recursive form using Euler method:

$$p(t + \Delta t) = p(t) + \Delta t(r(1 - \frac{p(t)}{m})p(t) - H_i p(t)), i = 1, 2, 3 \tag{28}$$

Table 6: Calculated Policy Result for Mara North Conservancy

Symbol	Percentage
K'_E	0.7094
K'_T	0.0006
H'_1	0.5187
H'_2	0.0295
H'_3	0.3453

6.2 Parameter Determination

6.2.1 r estimation

To determine the natural growth rate r, we use the exponential growth model to fit the existing population, since we suppose the natural growth rate r to be a constant and it is easier to fit it using this model:

$$p = p_0 e^{rt} \tag{29}$$

Above is the fitting result of the natural growth rate of elephants: (Population data are taken from [2])

Using the same method, we yield:

Table 7: Natural growth rate fitting result

Species	r fitting value
$Elephant$	0.0707
$Zebra$	0.0120
$Lion$	0.0209

6.2.2 m estimation

We develop the following model to determine the land carrying capacity of the animal population m:

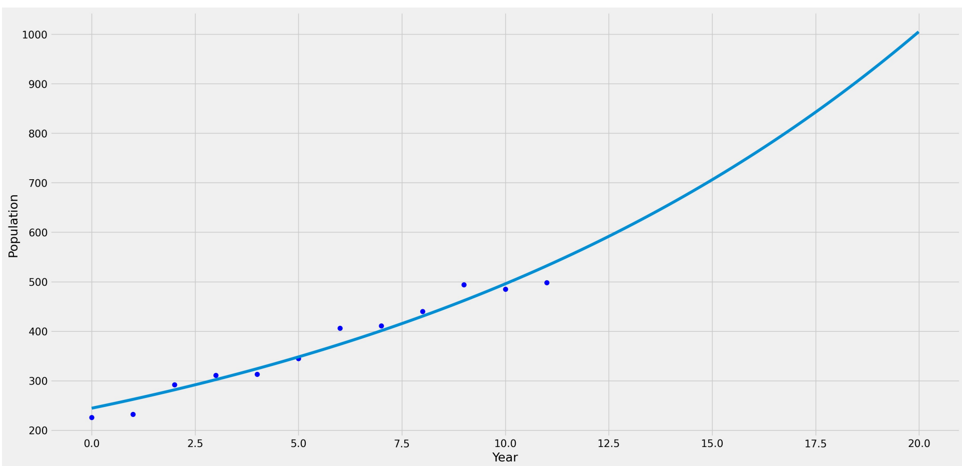


Figure 5: Exponential Regression to Estimate r value

$$m = \frac{M_{total}}{S} \tag{30}$$

By inserting the area of Maasai Mara game preserve[1] and the total land carrying capacity M_{total} for each species[7], the result of m is obtained:

Table 8: Land carrying capacity result

Species	m fitting value
$Elephant$	0.2
$Zebra$	18
$Lion$	0.36

6.3 Long Term Hunting Profit

Let $Pr_h(t)$ denotes the hunting profit at a given time t. Then we have:

$$Pr_h(t) = H_i P_i p(t) \tag{31}$$

, where P_i represents the profit that can be gained after hunting one animal and $p(t)$ represents the population of the animal at time t, which can be calculated from above recursive equation.

Below is the result of the long term hunting profit: (fig.6)

6.4 Long Term Ticket Revenue

All the ticket revenues are calculated in the same way as before, except for the animal density. Unlike the previous short term model, in which the density is ascertained using the estimated next year density level to provide some negative feedback of lose of animal to economy, there is no need to add such feedback under a long term prediction. Using the long term population model we developed, we can calculate the animal density at every t. To calculate the long term ticket revenue, we just plug in the animal density calculated at the same t, and then calculate the estimated tourists and price the same way as discussed in problem 2. The result is shown in the below diagram: (fig.7)

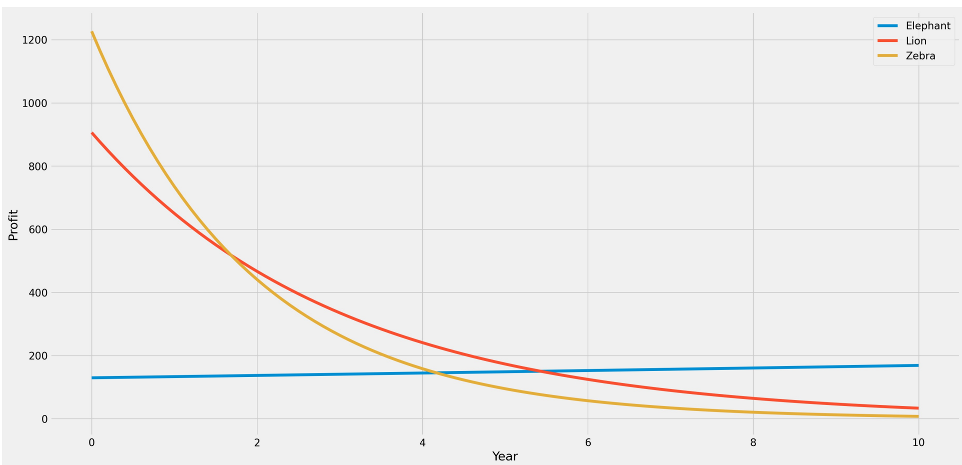


Figure 6: Long Term Hunting Profit

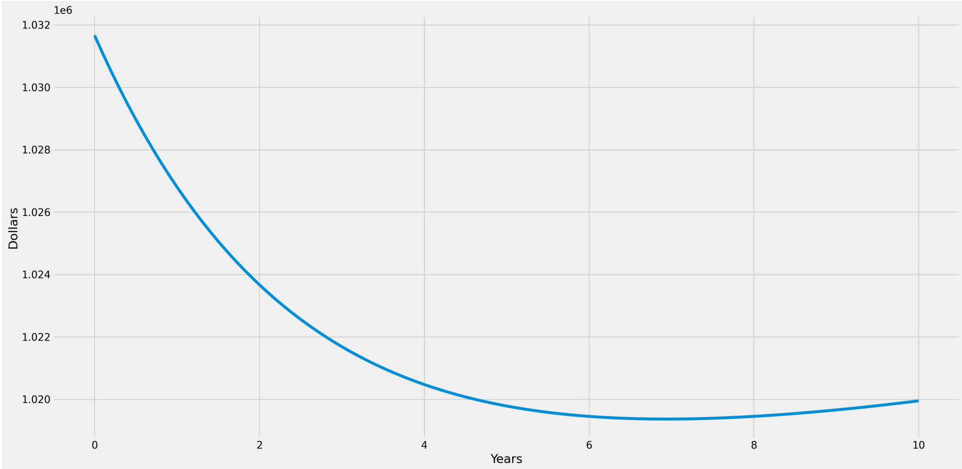


Figure 7: Long Term Ticket Profit

6.5 Total Economic Impact

Summing up the long term hunting profit and long term ticket revenue at every t, and then adding and subtracting other economy influence factors as discussed in problem 1 and 2 yields the estimated total long term economic outcome: (fig.8)

6.6 Result Discussion and Long Term Optimization of the Original Method

From previous diagram we notice that: though the combination of policies calculated from the method of problem A and B can provide the optimist balance of short term economic profit and wild life protection, in long term, the profit tends to fall continuously and the wild lift population also continuously decreases.

In fact, as long as the population of wild animals are decreasing, the long term economic profit will decrease continuously with it, since when the density of wild animals decreases, the ticket revenue decreases and when the number of wild animals decrease, the hunting revenue decreases.

Therefore, in order to keep the long term economic benefit continuously rising, we mush

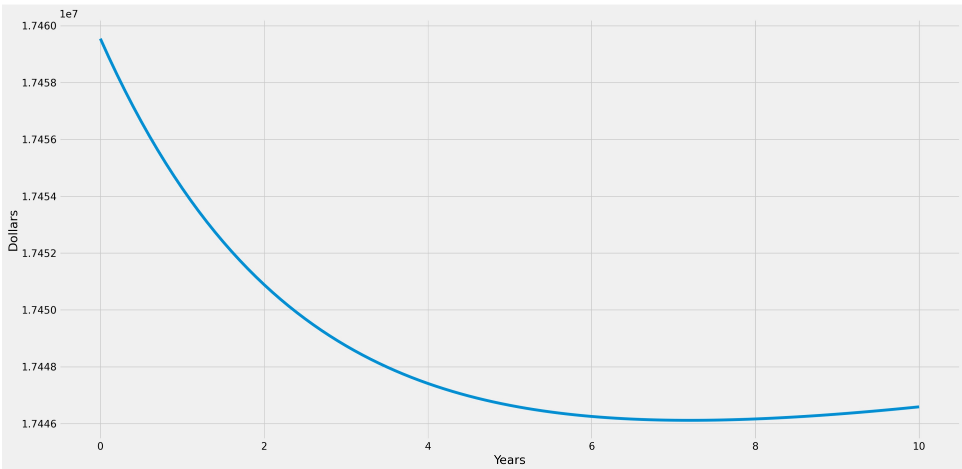


Figure 8: Long Term Total Profit

ensure the population of wild animals not to decrease. This also serves the function of animal protection. Using this logic, our model can be optimized in long term by adding the constraint: (This follows the notation in 5.1, formula(6))

$$r_i(1 - \frac{p}{m_i})p - H_i p \geq 0 \tag{32}$$

for every animal i considered. This reduces to:

$$H_i \leq r_i(1 - \frac{p}{m_i}) \tag{33}$$

Because the right side of the inequality is known, we just need to change range of every H_i from $[0, 1]$ to $[0, r_i(1 - \frac{p}{m_i})]$.

Using this method to re-perform the simulated annealing algorithm yields: (Figure 9 to figure 12)

From these four diagrams, it can further been seen that if we guarantee the animal population not to diminish, in the long term, the profit will keep incresing and the environment will also be better protected. However, from the aspect of profit in the near term, still, using the original method can be much more profitable.

6.7 Apply Model to Other Scenario

In general, the model we have developed can be easily adapted to another scenario. The data needed to be provided while making the policy is only the total space of the region, and the quantity of original elephants, zebras, and lions. After getting these raw data, one can instantaneously get the calculated result. Therefore, the model developed in this article can be a strong supplement for policy making in other regions.

7 Strength and Weakness

7.1 Strength

- In this model, we adopt discrete optimization method to get the theoretical best policy to balance the environment protection and people's well being.

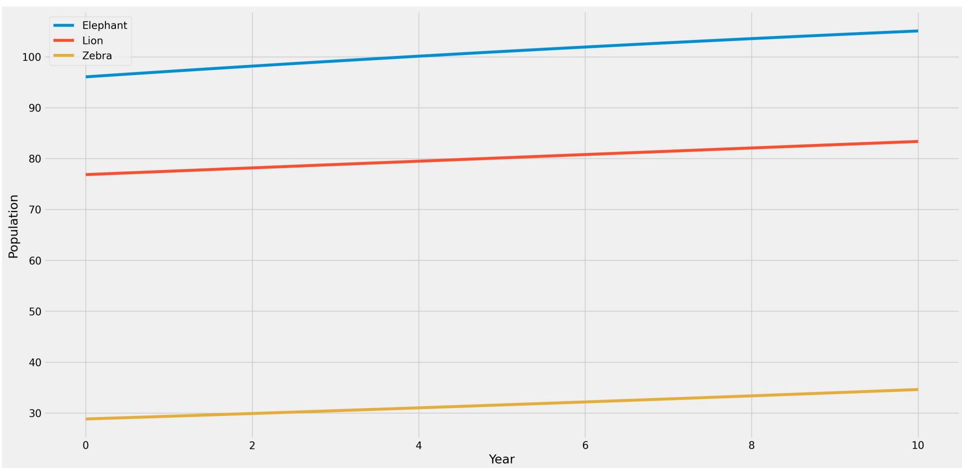


Figure 9: Optimized Long Term Population

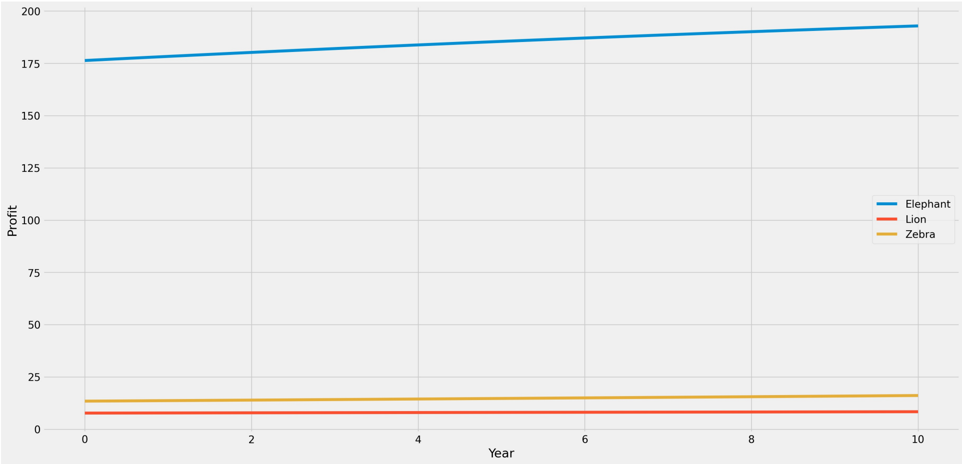


Figure 10: Optimized Long Term Hunting Profit

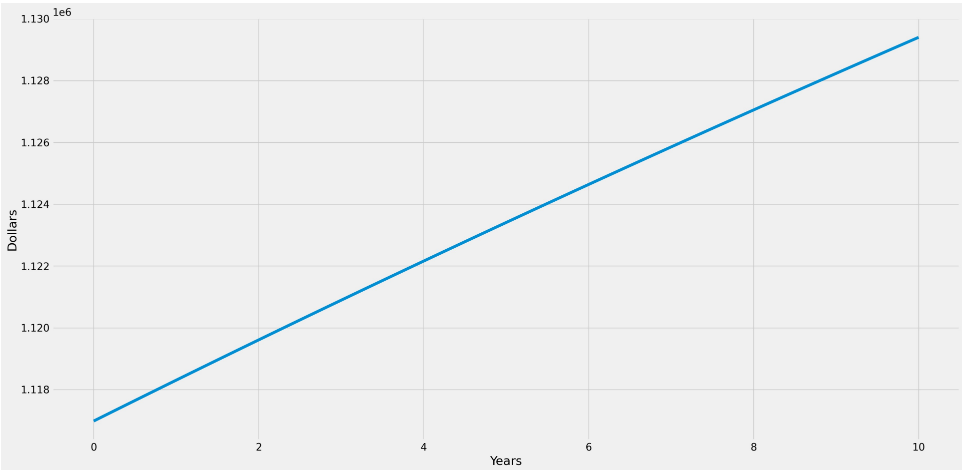


Figure 11: Optimized Ticket Revenue

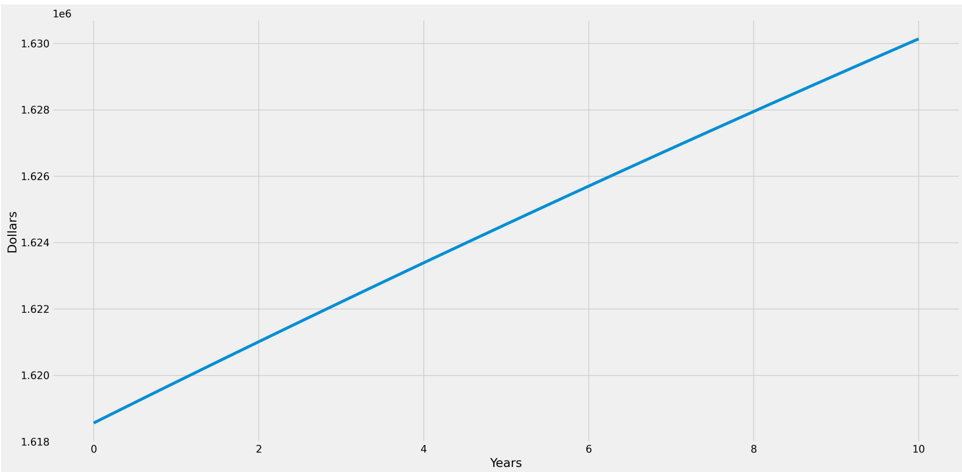


Figure 12: Optimized Long Term Total Profit

- We provide two models that can be adopted to different needs of the stakeholder. (Whether they want to make more profits or pay more attention on environment protection)
- To estimate the economic impact of our policy, we develop a strong economic model that is analogous to real life.

7.2 Weakness

- We use simulated annealing to solve for the optimization problem. However, the simulated annealing algorithm can only provide an approximate solution while not able to give accurate solution. Therefore, some errors will inevitably be formed in our model.
- We use a large amount of regression to support our research in this article. However, in real life, these data pairs may only be loosely related to each others and therefore the estimation from linear model will produce great error.

8 Conclusion

In conclusion, we consider recommending policies relating to the exploitation of land and hunting restrictions.

For every policy, we develop two models corresponding to the evaluations of the negative impacts on animals and economics profit to the local people respectively. We combine the four submodels into one formula by subtracting the scaled economics profit using the scaled negative impacts, and use simulate annealing to find the values of hunting proportion and the variables describing land allocations when the result of formula is maximized.

We also use our logistic model to take animal population change into consideration to and deduce an alternative policy that does not dimish the population of animals.

Finally, our recommendations are listed below:

1. Legalize while strictly regulate the bushmeat market, restrict the hunting quantity in the optimal hunted percentage range. To be more specific, Limit the percentage of lions, zebras, and elephants caught per year to 0.155, 8.535, and 1.080.

In order to manage the application of this policy, the government need to stricktly regulate the bushmeat market according to the proportions, punish secret trades, and regulate the quality of the bushmeat.

2. Restrict the land exploitation. The whole area of exploited land in the Maasai Mara should not be more than 382.03 square kilometers, while the exploited area for tourist accommodation and infrastructure should be well managed in the optimal park exploit percentage range. Exploit 25$\%$ of the total area, 2.9$\%$ for tourism exploitation, 382.03 square kilometers of total exploited area, 43.79 square kilometers of exploited area for tourism.

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