Problem Chosen	2023 MCM Summary Sheet	Team Control Number
B		2307381

Brand New Maasai Mara“s”

Abstract

How to balance the development of economy and the protection of wildlife in Maasai Mara has been a focus of global concern for a long time. The wildlife quantity has declined sharply in the past ten years. Worse still local economy has been negatively influenced by conflict between local people and wildlife and the covid 19 epidemic. Adjusting policy and management of Maasai Mara is extremely urgent.

For the first task, we sperate the preserve and its surrounding area into nine regions according to their landscapes, rainfall, etc. Digging into historical causes to the current condition, based on real world data including tourist quantity and local animal husbandry features, revealing linearity of relation between rainfall and farming income factor α, predicting tourist quantity in 2023, and distribution of accommodation, we manage to establish a **discrete model** to assess farming efficiency, predict tourist quantity, and predict consequent interaction between wildlife and human. With such indexes, specific policies and strategies are proposed, i.e., several recommended allocations of industrial land use.

For the second task, an **interaction quantification model** using data fitting is proposed. By analyzing the relationships among data, we concluded that wildlife density is influenced by both human density and livestock density, which reflect the pattern of interaction between them. Besides, a **multi-objective optimization model** is established. The objective function takes both economy and ecosystem into account, and **Genetic Algorithm** is adopted to obtain the best combinations of variables. The best policy and strategy turn out varying in different regions, which indicates that a re-allocation of land used for agriculture, animal husbandry and tourism can indeed reach a better balance between the locals' interests and wildlife protection. For example, an optimal land use management for one of the subregions near Maasai Mara National Reserve, which we name as CSV2, allocates 83.08% of its total area for tourism, 8.26% for agriculture, and 8.66% for animal husbandry. Meanwhile, another region, TM3, allocates 70.94% for agriculture, 7.11% for animal husbandry, and 21.95% for tourism, which fits our intuitive conjecture based on farming efficiency and distance to National Preserve well.

For the third task, a prediction for long-term trend of the preserve with our strategy is offered first. By coarse analysis, a potential profit of 3×10^7 dollars can be attained by progressively adjusting the land utilization according to our strategy. Since parameters can be adjusted according to associating features of different areas, our methodology is proved powerful enough to be applied for better development of other natural reserves as well.

Key words: “Nine-Subregion” Discrete Model, Interaction Quantification Model, “Economy-Ecosystem” Multi-objective Optimization Model, Genetic Algorithm

Contents

1. Introduction

1.1 Problem Background

Maasai Mara, located in southwest Kenya, East Africa, has been considered one of the most fascinating natural reserves throughout the world. However, conflicts between humans and nature have never stopped near the region. Centuries ago, while this piece of land of Africa was still away from industrialization and modernization, the locals would have to fight, compete with beasts and droughts, and thus protect their crops as well as livestock from being disturbed or plundered.

Decades ago, while the modern government was taking control of the region, organized agriculture and animal husbandry within the region was setting off, which kept consuming natural resources in the savanna and formed a land-use-competition with wild animals. Getting closer to the 21st century, as the rest of the world started to realized value of natural resources and an ideal environment, yelling for eco-protecting development, the Kenya government formulated harsh environmental protection policies [11], driving way local people in protected natural preserves and began to limit the traditional nomadic way of production.

Later, the Kenya government demonstrated its strong interests in settled agriculture and encouraged people to farm more in wet meadow at boundaries of pastoral area by the side of natural preserves, because of both higher potential profit of modern agriculture, and government's need for "community buffers" around the natural preserve [12]. This might have indeed benefited the maintenance of land cover in protected areas and to some degree, reduced the impact of animal migration on people's life and normal production. However, with such strict protective policies, the estimated number of wild animals in the region has dropped by around 60% in the previous decades [13] , and thus the strongly biased protective strategy has been criticized by countless research. Some point out that the policy deprived the indigenous people of their livelihoods and failed to help them fit in the new society, which led them to poaching and other illegal activities. Others state that the emphasis on agriculture development vastly consumes the national land resources and accelerates the process of land privatization due to the unsound financial credit system[11], and foremost, settling down and dividing lands for farming do contribute to the acceleration of savanna degradation and thus result in the eventual decrease in number of wild animals[13].

In general, a thoroughgoing protective policy may go in opposite direction towards protecting wildlife and natural resources, and is more likely to hinder to people's current welfare and further progress for their ideal living status. Therefore, for not only proper protection of wild animals and natural resources but also better welfare for people and economic development, harmonizing among nature protection, animal husbandry, and agriculture industry is obviously far more complexing than just emphasizing on one dimension.

1.2 Problem Restatement

Aiming to solve this issue, this research will offer analysis and methodologies based on historical or real-time data and achieve the following objectives:

- **Requirement 1** asks to enumerate several specific policies and strategies that simulates strategies that used to be in real application or proposed and recommended by our team, one of which is supposed to reach the most acceptable balance between individual interests and wildlife preservation.
- **Requirement 2** asks us to establish an evaluation method to rank and compare the enumerated policies and strategies with our assessment criteria.
- **Requirement 2** also asks us to construct, describe, and analyze a linkage system of specific strategies for specific industries that lead to consequent interactions between animals and people, as well as overall economic outcomes.
- **Requirement 3** asks us to propose our selected strategy, analyzing impacts of the strategy in long-term, and predict how the strategy can be applied generally to other wildlife management areas.

A short report for the Kenyan Tourism and Wildlife Committee will be appended at the end of this research, which will demonstrate our proposed plan and how it will benefit the entire preserve.

1.3 Our Work

Maasai Mara reserve is a large area covering 6,500km². First, we divide this area into nine parts to make our reallocation more accurately. In each region divided, different percentage of the industries means different strategies. **In section 3.1,** we first built the model to evaluate how well each allocation policy balances the interests of people and in the meantime protect wildlife and natural resources. Then, **in section 3.2** by using regression analysis and the materials found in the database, we successfully set up a human-animal interaction model. This model explicitly reveals the relationship between the density of wildlife and the local population density as well as the livestock density. After that, **in section 3.3,** based on the model built in **section 3.1,** we successfully build an equation to describe the effectiveness of protecting the environment.

In **section 4,** we use the model built in **section 3** to evaluate the adjusted allocation policy compared to the previous one. After that, in **section 5,** we attain the optimized results with genetic algorithm. Furthermore, in **section 6,** we predict and analyze probable long-term impacts of our strategy on the preserve. How our strategy can be applied to other preserves is also discussed, along with possible future work that can be built upon the result of our research.

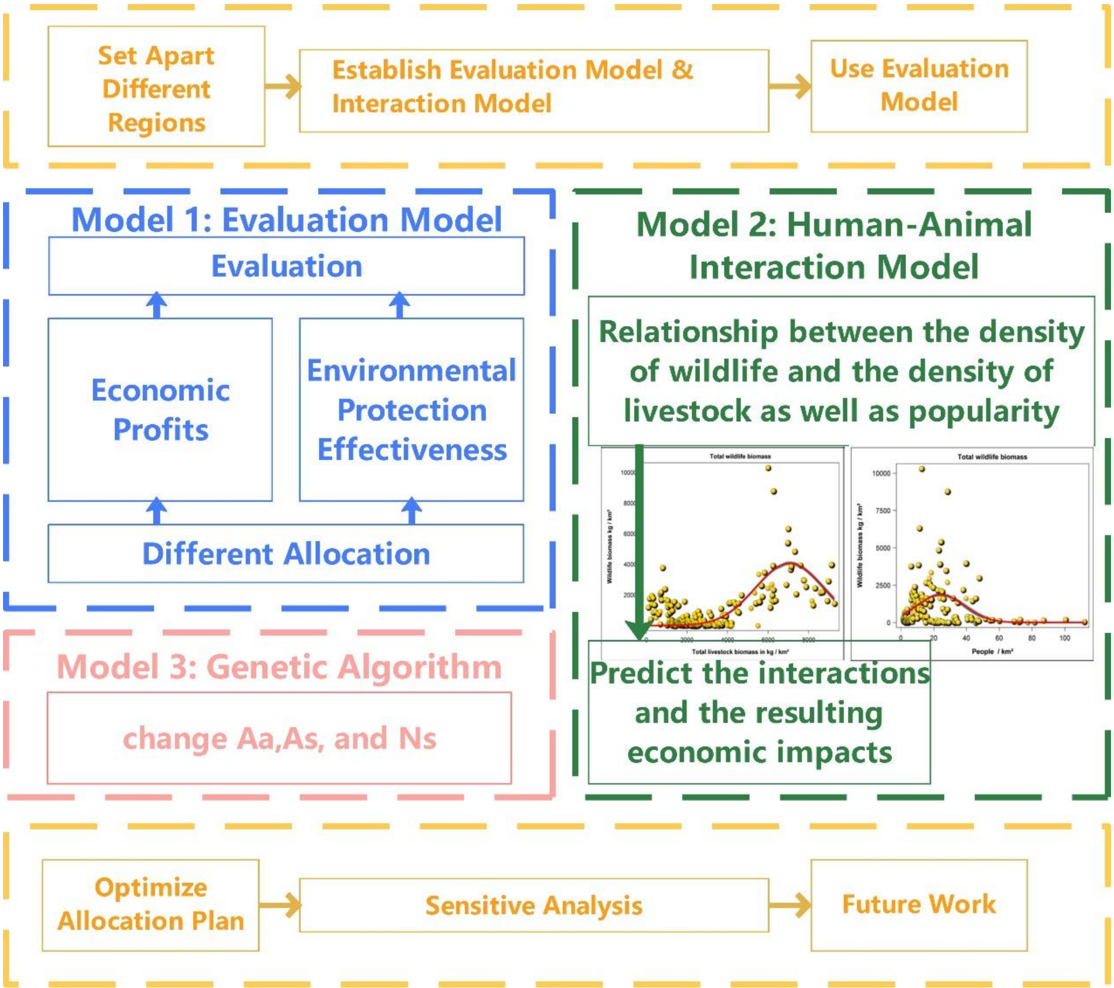

Figure 1. Demonstration of Our Work in the Research

2. Assumptions and Notations

2.1 Assumptions

Through the full analysis of the problem, in order to simplify our model, we make the following reasonable assumptions.

Assumption 1 The total area of a given region is a fixed constant.

Assumption 2 The land has three main uses, farming, agriculture, and preserve.

Assumption 3 The total amount of tourists visiting Maasai Mara will not change in a short time and can be predicted from previous years data.

Assumption 4 Outcomes of farmlands vary among different regions.

Assumption 5 Proportion of species of livestock in Narok County is close enough to that in the whole nation.

2.2 Notations

Table 1. Notation

Symbol	Definition
λ, μ	$coefficients\ for\ assessment\ model$
$P_{ag/ah/tm}$	$outcomes\ of\ agriculture/animal\ husbandry/tourism$
P_{total}	$total\ profit\ of\ agriculture\ \&\ animal\ husbandry\ (for\ smallholders)$
P_{gov}	$total\ profit\ of\ tourism\ (for\ the\ government)$
$A_{ag/ah/tm}$	$areaforagriculture/animal\ husbandry/tourism\ (preserve)$
A_{total}	$total\ regional\ area$
p_0, α	$average\ profit\ of\ agriculture\ per\ hectare\ and\ its\ associative\ coefficient$
p_1	$price\ of\ tickets\ for\ tourism\ (profit\ per\ person)$
q_0	$profit\ of\ animal\ husbandry\ per\ stock\ on\ average$
$N_{t/s/w}$	$amount\ of\ tourists/livestock/wildlife$
$D_{t/s/w}$	$areal\ density\ of\ tourists/livestock/wildlife$
u, v	$linear\ coefficient\ of\ D_w(D_t),\ D_w(D_s)$
e	$index\ for\ nature\ protection$
E	$notation\ for\ optimal\ balance\ of\ nature\ protection\ and\ locals'\ insterests$

3. Models Establishment

By reading the relevant materials, we find out the land use in Maasai Mara region mainly are Preserve, Pastoral, and Cultivated, as shown below the figure (). However, this allocation might be improper. For example, at the border between Maasai Mara National Reserve and Koyiaki, the human-animal conflict is intense. Livestock are eaten by large carnivores like lions. And locals' life is also threatened. Therefore, in Koyiaki region, it will be more proper to increase the proportion of protective tourism, which means more land should be used as reserve area, thus mitigating the conflicts and in the meantime bringing economic benefits.

In order to evaluate and optimize the policies and management of different areas within and around Maasai Mara, considering the current ratio of agriculture, stock farm and tourism, we firstly divided the whole region to Maasai Mara National Park, Conservancies and Trans Mara three regions. Then, based on the analysis of economic efficiency of agriculture, stock farm and tourism, we divide the regions into subregions according to their distance from National Park and from main rivers, including MMNR1, MMNR2 (within Maasai Mara National Park); CSV1, CSV2, CSV3, CSV4 (within Conservancies); TM1, TM2, TM3 (within Trans Mara).

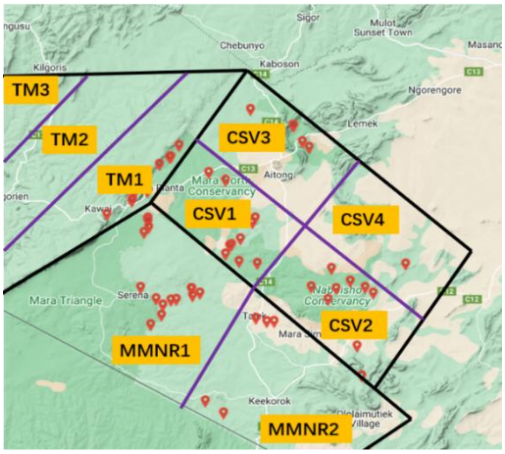

Figure 2. Sub-division of Our Study Area

Figure 3. Accommodation in Our Study Area

Our basic idea is to build up an objective function, taking both economic and environmental factors into account. To represent the economic effects, we use the profit as an indicator – u shown in the Figure. 4. And to represent the environmental protection effects, we first figure out the interaction between wildlife and people as well as between wildlife and livestock, w, v, respectively. Based on these interactions, we build a formula to describe how well the protection effects are.

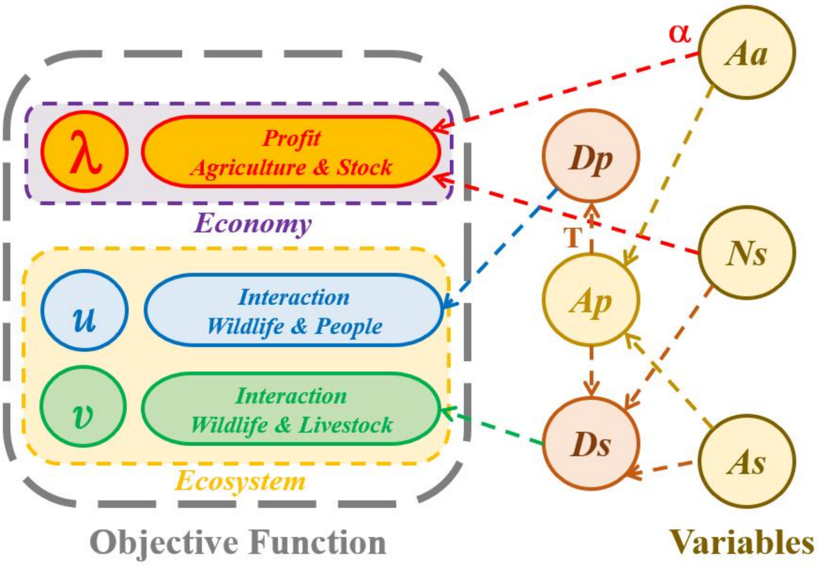

Figure 4. Objective Functions and Variables

3.1 Overall Model for Assessment

To evaluate different policies, we establish an evaluation model, taking the economic profit and the effectiveness of protecting the environment into account, which is:

$$E = \lambda P_{total} + \mu e \quad (1)$$

As for the equation to evaluate the effectiveness of protecting the environment, it will be shown in **3.3,** since we need to use the equation built in **3.2.**

The total profit can be represented in form:

$$P_{total} = P_{ag} + P_{ah} + P_{tm} \quad (2)$$

As for the profit of agriculture:

$$P_{ag} = \alpha p_0 A_{ag} \quad (3)$$

The profit of animal husbandry:

$$P_{ah} = q_0 N_s \quad (4)$$

Of tourism:

$$P_{tm} = N_t p_1 \quad (5)$$

Since the area is fixed, we also have:

$$A_{total} = A_{ag} + A_{ah} + A_{tm} \quad (6)$$

3.1.1 Evaluating Profit of Tourism

According to the equation [5], first we need to derive the total number of tourists.

Assuming the total number of tourists visiting Maasai Mara will not change in a short time and can be predicted from previous years data, the goal of this part is to make a prediction of the tourist quantity in 2023.

Firstly, data collection. We collected data on number of tourists visiting Mara Triangle, which is the west part of the Mara River within Maasai Mara National Preserve, in the previous years and data on number of tourists visiting Maasai Mara of limited years. Due to the incompletion of direct statistics on the number of tourists visiting the whole national preserve, we decided to predict the tourist quantity by interpreting data of part of the national park, i.e., Mara Triangle [1], and the relationship between Mara Triangle and Maasai Mara.

Table 2. Annual Number of Tourists in Maasai Mara and Mara Triangle

Tourists	**Maasai Mara (MM)**	**Mara Triangle (MT)**	**MT / MM**
2015	146900	90000	61.27%
2016		113213	
2017		107254	
2018	291017	145238	49.91%
2019	311882*	157591	50.53%
2020	71500	45328	63.40%
2021		68349	
2022		121471	
Correlation	**0.9957**		
Average		**56.37%**	
Variance		**0.061**	

Table 3. Monthly Visitor Arrivals into MMNR for the Period 2018-2019

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
2018	9396	11,870	12,836	9031	10,969	26,409	54,365	59,974	28,003	23,009	14,458	30,697	291,017
2019	13,775	15,963	9124	11,190	7929								

Secondly, data analysis. from the data and figure of annual quantity of tourists visiting Mara Triangle, several trends can be concluded:

1) The assumptions that Mara Triangle had a steady proportion of tourists compared to the total number of Maasai Mara and Maasai Mara has the same trend as Mara Triangle with respect to the quantity of tourists are reasonable. Since an average proportion of 56.3% can be obtained from four years of data [2][3][4] comparison and a variance of 0.06 is acceptable. Specifically, based on data in 2018 and part of 2019 [2] collected from authority, a high fitness between these two years made it possible for us to obtain a reliable digit in 2019 by computation.
2) A sharp decline took place in year 2020, which shows the reality that tourism in Maasai Mara is relatively hugely influenced by Covid-19 epidemic.
3) Simultaneously, a boom can also be seen from 2020 to 2022 at a relatively fast speed compared with the period from 2013 to 2019, which reflects the fact that Maasai Mara is recovering optimistically from the pandemic though it did not completely rise back to the peak in 2019.
4) The general trend of rising from a global view before 2019 shows that quantity of tourists would increase relatively steady if the epidemic did not cut in.
5) The explicit data on quantity of tourists from 2013 to 2022 is worthy of consideration when we do the prediction.

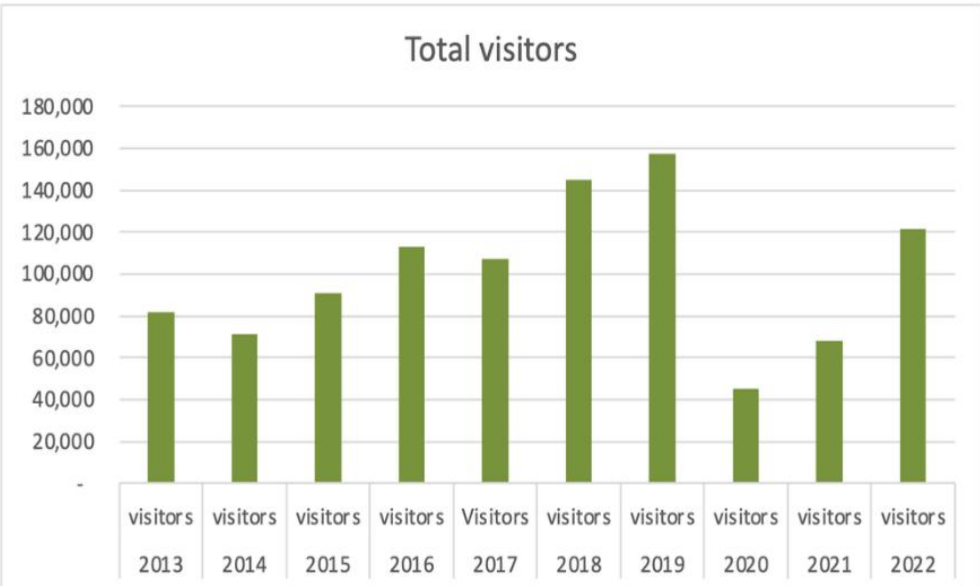

Figure 5. Annual Distribution of Visitors

Based on these interpretations, we fit the annual data of Mara Triangle with the proportion coefficient with functions of different degree separately according to before and after epidemic, i.e., 2020. More specifically, by comparing the variance between regression function and actual data, we decided to use quadradic function instead of linear regression to fit the data from 2013 to 2019 and from 2020 to 2022 with variance of $\mathbf{921582754.565264}$ and $\mathbf{3.9 \times 10^{-9}}$. These two contributions help our prediction follow the current and general trend. Besides, a linear regression of data from 2013 to 2019 and the direct computation of average value reflected the actual potential and relatively steady in the long run.

Table 4. Algorithm 1 to Predict Number of Visitors

Algorithm 1: Discontinuous Data Prediction by Non-linear Regression (DDPR)	
1	Divide data by discontinuity, i.e., year 2020
2	Regression on global data, reflect global trend
3	Regression on data before discontinuity, reflect former trend
4	Regression on data after discontinuity, reflect recovery trend
5	Average of all data
6	Add all functions above with weights
7	Prediction & Evaluation

Thirdly, result. Within a small variation, we predicted that there will be **303842** tourists visiting Maasai Mara in 2023.

Fourthly, average profit from tourists. According to [6], the native tourism profit of locals is mainly from offering accommodations including camps and lodges to tourists directly or indirectly, i.e., managing accommodation business themselves or collecting lease fee from travel agency that offers accommodations. Theoretically by analyzing prices of accommodations in 9 regions, we can obtain the economic efficiency for tourism. Similar to [2] but changing the model to be discrete, we proposed a varied-distance classification discrete model on different regions within Maasai Mara.

Next, data collection. Due to a lack of official statistics on tourism income in different regions in Maasai Mara, we decided to interpret data from travelling agencies. On online booking website [5], the price for accommodation of two adults for April 1st one night is searched. Average price then is computed. Proportion of accommodation is computed by dividing the number of camping sites over the total number of camping sites. Income then is calculated by multiplying the number of customers and the average price.

Then, result interpretation. It is obvious that subregions that are closer to National Reserve benefit more from tourism since they have more tourists and higher level of personal consumption. As we assume that the trend of number of tourists visiting Maasai Mara will not change in a short period, the natives' tourism income of these subregions will not change either.

Table 5. Income from Tourism (1)

Tourism	**MMNR1**	**MMNR2**	**CSV1**	**CSV2**
Average Price	577.6	316.5	791.7	869.8
Proportion of Acco in total	24.39%	26.83%	14.63%	14.63%
Customer ($\times 10^3$)	74.10	81.52	44.45	44.45
Income ($\times 10^6$)	21.40	12.90	17.60	38.66

Table 6. Income from Tourism (2)

Tourism	CSV3	CSV4	TM1	TM2&3
Average Price	444.5	162.0	460.5	11.0
Proportion of Acco in total	4.88%	2.44%	9.76%	2.44%
Customer ($\times 10^3$)	14.83	7.413	29.65	7.413
Income($\times 10^6$)	3.296	1.201	13.65	0.082

3.1.2 Evaluating Incomes from Agriculture (α)

Agriculture in Maasai Mara and its surrounding areas is under great influence of the climate features that all typical savannas in tropics share -- high temperature and unevenly distributed annual rainfall. Both distributions of rainfall time and space, that is, amount of available water associated with specific time and location, serve as a main constraint for outcomes. The constraint and the actually dramatical rainfall result in a special form of organization for agriculture production in Kenya – "**transient farming**", while which smallholders cooperate with external capital and grow cash crops within the short rainy season, mostly making use of wet sand land or wet land by sides of transient rivers formed by intensive rainfalls [14] In fact, this pattern has occupied around **75%** of agriculture land in Kenya [14] which effectively shares risks with smallholders and increases overall agricultural outcomes on a considerable degree through utilizing marginal land resources. Since this research focuses on balancing nature preservation and interests of local people, overall income of smallholders is supposed to be an ideal measurement indicating part of the economic outcomes and people's interests.

According to a report from the Food and Agriculture Organization of the United Nations in 2015, the average annual income of smallholders in Kenya from per hectare of farmland is estimated to **$888** [15] in which around 75% percent is contributed transient farming, as is pointed out previously. Basically, this part of income is free from stable water supply and almost completely relies on soil moisture contents. As rainfall data from Kenya Meteorological Department states, temperature in Kenya rarely varies much throughout a year (minimum around 16 and maximum around 28 Celsius degrees in a day) [16] that is, the rate that moisture in soil evaporate at is distributed uniformly along time. Therefore, to evaluate the relative annual productivity of farmlands in unit area, it would be quite reasonable to evaluate annually **accumulated soil moisture content** of farmlands, which limits the production duration of farmlands in a year. Moreover, considering all three factors including soil moisture content, the quantity of rainfall, and the rate of evaporation, such duration appears with finely **linear** relationship with index of rainfall [17] Consequently, to estimate regional differences of annual production of unit farmlands in Kenya, it would be fair enough to take only regional annual rainfall into our consideration, which would directly influence the 75%-part of average income of smallholders.

For the rest 25% of average income, depending on location of constant river, would be within 200m to riverbanks for smallholders, looking for irrigation's convenience [14], which means that installation of larger scale will be introduced by capital, as more percentage of outcomes will be carried by capital. Focusing on relative income for smallholders, we reasonably neglect difference of this 25% of average income due to regional factors. That is, 25% of $888 will remains the same for each area.

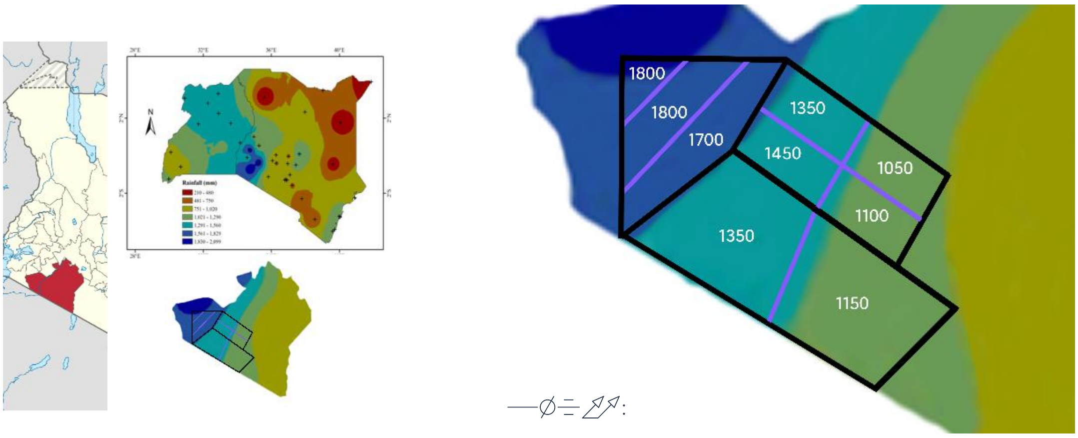

Figure 6. Areal Distribution of Rainfall in Kenya/Narok County

As is shown in Figure. 6, through overlapping the map (left) indicating location of Narok County and the map (middle-top) demonstrating space distribution of rainfall in Kenya, we acquire the map (middle-bottom) with space distribution of rainfall in Narok County. Zooming the map for the whole Narok County, considering rainfall interval where each of our research areas is, and applying non-linear approximation, a map (right) with estimated annual rainfall marked for each of our research area is eventually obtained. As a result of area integral of rainfall with estimations that around 40% of land in Kenya has been farmlands, the estimated annual rainfall on average of farmlands in Kenya turns out to be around 1000mm. Thus, estimated average income per hectare of farmlands P_i for smallholders in region i can be represented as:

$$P_i = \left(\$888 \times 75\% \times \frac{r}{1000mm}\right) + \$888 \times 25\% \quad (7)$$

, in which r is notation for estimated annual rainfall marked in Figure A.

In coordination with previous formulas, we would like to denote the equation as:

$$P_i = \alpha_i P_0 \quad (8)$$

, in which $P_0 = \$888$, and α_i is considered as regional efficient for individual's profit of region i from per hectare of farmland:

3.2 Assessment of Human-Animal Interaction

With respect to the interaction between people and wildlife, many factors including benefits such as pastoralists relying on number of stocks they have, grassland needing stocks and wildlife to maintain and conflicts such as wildlife eating stocks, hurting people, treading crops. According to [7], population density of main wildlife species, such as Burchell's zebra, Buffalo, Elephant, Ostrich, Wildebeest, Giraffe, Grant's gazelle, Warthog, Thomson's gazelle, Eland, Topi, Hartebeest, Impala and Waterbuck is significantly influenced by changes in people density and livestock biomass. To simplify our model, we narrowed our relationship analysis to Narok.

Data collection [7]. The amount of stock is the summation of annual quantity of sheep and goats, Donkey, and Cattle in Narok. The wildlife quantity is the summation of 14 wild animals listed above. The density then is amount divided by area of Narok, which is **15263km²** [8].

Pairwise relationship mining. By fitting scatter diagram, we found the pair-wise relationship between stock density, people density and wildlife density. Although the variance is large, such relationships can be inferred from the fitting diagram to some extent. It can be interpreted that as stock increases, more grass and lands are occupied by stocks, causing a declination in wildlife. As population increases, more lands, resources are obtained by people and pollution gets severe, causing a declination in wildlife.

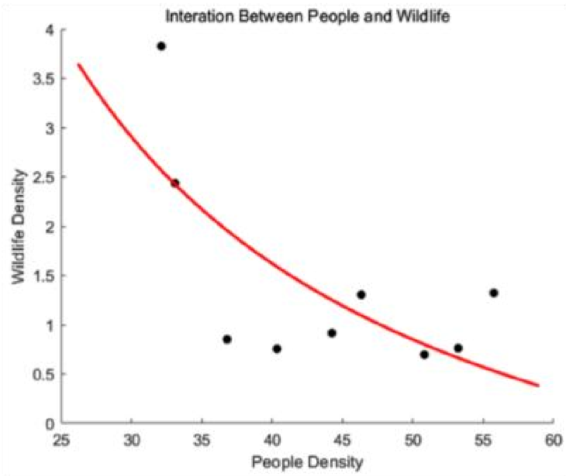

Figure 7. Relation Between Density of Wildlife and Density of People

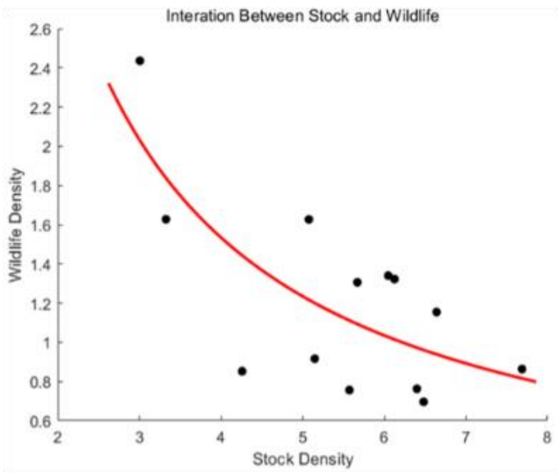

Figure 8. Relation Between Density of Wildlife and Density of Livestock

To obtain a more direct and accurate relationship between wildlife and local people, we considered the result from
[7].

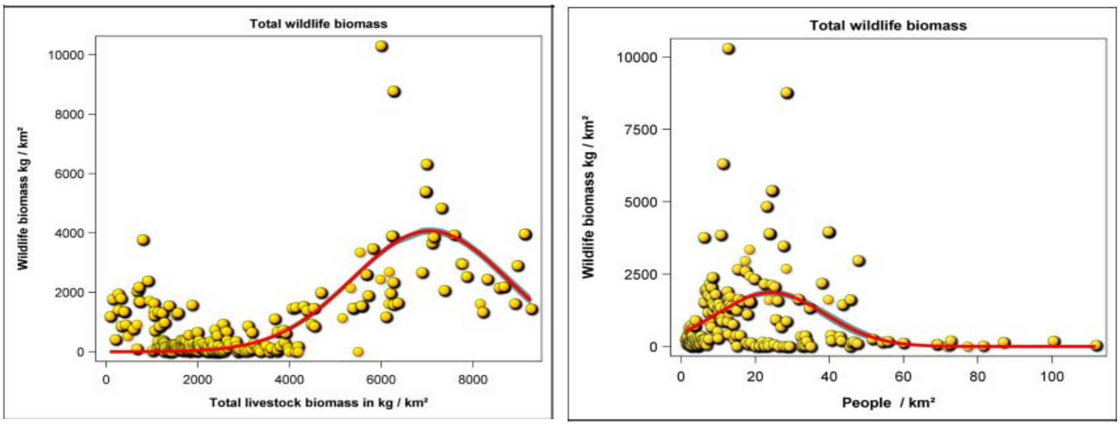

Figure 9&10. Relation Between Wildlife Biomass and Livestock Biomass/Density of People

The data is collected onsite including data of different kinds of wild animals and different kinds of stocks of the past 40 years in different regions in Kenya, so it is reliable and useful. From the scatter diagram, we can see the fitting curve showing specific relationships between wildlife quantity and livestock quantity, wildlife quantity and people quantity. By fitting the scattering points and changing biomass into density, the relationship is concluded as follows:

$$D = \frac{N}{A} \quad (9)$$

$$D_w = \begin{cases} -0.183{D_S}^2 + 5.045D_S - 27.18 & D_w > 0 \\ 0 & D_w \leqslant 0 \end{cases} \quad (10)$$

$$D_w = \begin{cases} \dfrac{154.1775}{D_p} - 2.2329 & D_p > 22 \\ 13 & 0 \leqslant D_p \leqslant 22 \end{cases} \quad (11)$$

These formulas are used as part of our objective functions, representing the ecosystem protection efficiency, which is one of our main targets. Specifically, formula (7) reflects the interaction between wildlife and livestock, a given number of livestock can be beneficial for the thrive of wildlife, but when it exceeded the optimal point, it has negative impact on wildlife. A quadratic function can suitably show this trend of conflict and mutual benefit. Formula (8) reflects the interaction between wildlife and people, mostly they are in an reverse proportion to each other. Therefore, for our model, we simplified it with an inverse proportional function to show the mainly negative interaction between human density and wildlife density with a threshold at 22 people/km² suggested by [7].

3.3 Environmental Effectiveness Evaluation Model

We define notation "e" as the indicator to evaluate how effective the environmental protection is. We think the density of wildlife is highly related to the effectiveness of environmental protection. The higher the wildlife density is, the more effective the environmental protection is. Based on the relationship derived from **3.2,** we could derive e as a function of the density of wildlife.

$$e = v \times D_w(D_s) + u \times D_w\left(D_p\right) \quad (12)$$

Eventually, we have:

$$\begin{cases} E = \lambda P_{total} + \mu e \\ P_{total} = P_{ag} + P_{ah} + P_{tm} \\ e = v \times D_w(D_s) + u \times D_w(D_p) \\ D_w = \begin{cases} -0.183D_s^2 + 5.045D_s - 27.18 & ,D_w > 0 \\ 0 & ,D_w < 0 \end{cases} \\ D_w = \begin{cases} \frac{154.1775}{D_t} - 2.2329 & ,D_t > 22 \\ 13 & ,0 \leq D_t \leq 22 \end{cases} \\ P_{ag} = \alpha p_0 A_{ag} \\ P_{ah} = q_0 N_s \\ A_{total} = A_{ag} + A_{ah} + A_{tm} \\ P_{tm} = p_1 N_t \end{cases} \quad (13)$$

4. Specific Policies and Strategies

When it comes to different policies and management strategies, it's easy to list a few, including fencing, prohibiting poaching, and so forth [9][10]. However, it's difficult to compare the effectiveness of these methods due to their disparate purposes. Plus, concerning these strategies, they do not function separately but as a whole. Hence, it's not advisable to evaluate these singular policies and strategies.

Under such condition, we think it's more appropriate to look from a more macro and systematic perspective, which is considering the allocation of the land in the Maasai Mara region.

Based on the **Section 3.1.1** and the **Section 3.1.2,** the price of crops and the price of ticket for tourism vary among different regions. Some are higher than the average, while some are lower. Obviously, when its price is higher than the average, we are supposed to expand the proportion, vice versa.

We take MMNR1 region as an example, its crop price and ticket price are both relevantly high, therefore, we will expand the proportion of agriculture and tourism, which is 60% tourism, 30% agriculture, and 10% animal husbandry.

By the same method, we can derive the industry proportion of other 8 areas.

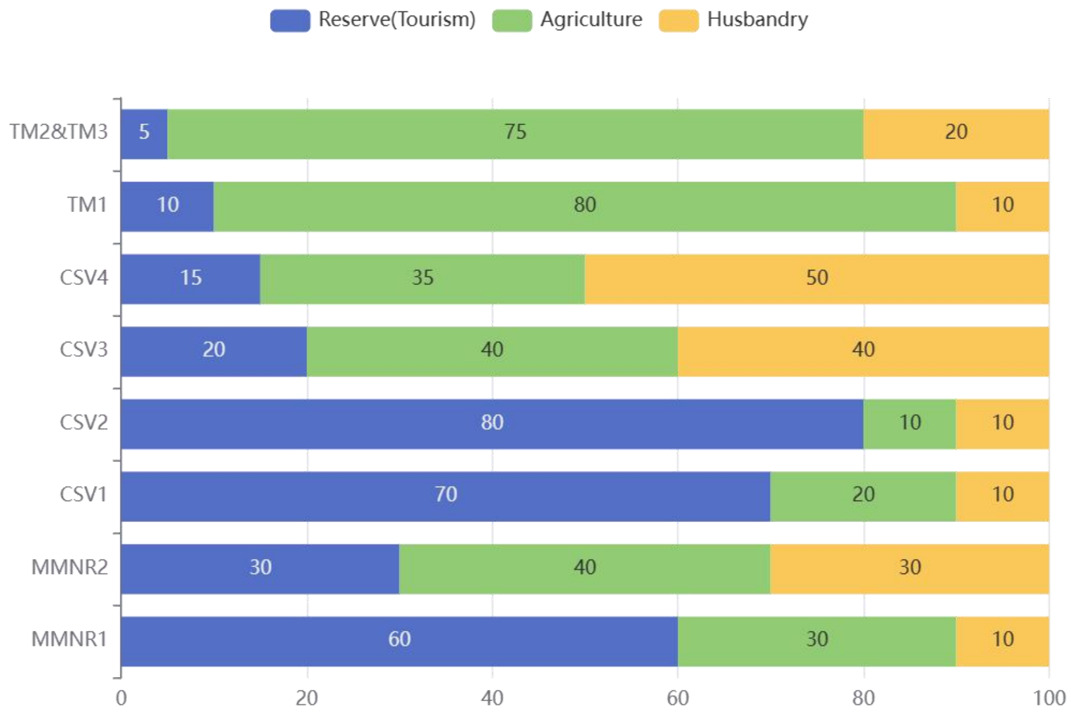

Figure 11. Industrial Strategies for Distinct Areas

5. Optimization of Strategies

5.1 Global View of Multi-Objective Optimization System

Our aim is to maximize E applying equation (1).

Table 7. Parameters of Distinct Areas for Optimization (1)

Parameters	**MMNR1**	**MMNR2**	**CSV1**	**CSV2**	**CSV3**
α	1.17	1.03	1.14	0.90	1.03
Area (km^2)	999.75	772.88	369.90	369.90	369.90
Tourist ($\times 10^3$)	74.10	81.52	44.45	44.45	14.83

Table 8. Parameters of Distinct Areas for Optimization (2)

Parameters	**CSV4**	**TM1**	**TM2**	**TM3**
α	0.83	1.55	1.55	1.41
Area (km^2)	369.90	660.52	421.32	144.22
Tourist ($\times 10^3$)	7.413	29.65	3.707	3.707

5.2 Method

Since three variables need to be changed to adjust the model during optimization of two objective functions, we proposed Genetic Algorithm to solve this multi-objective optimization problem. Specifically, we take the advantage of natural selection process, imitate the procedure of Selection, Crossover, Mutation to retain optimal combinations of variables and progressively approach the optimal result.

Table 9. Pseudo Code of Algorithm 2 for Optimization

Algorithm 2: Management Optimization based on Generic Algorithm (MOGA)	
1	Initialize 100 combinations of Aa, As, and Ns
2	For term = 1: 100
3	Evaluate each combination by objective function, sort, record best one
4	Selection, retain optimal ones
5	Crossover, change Aa or As or Ns with other combinations with P = 0.1
6	Mutation, change Aa or As or Ns to other random number with P = 0.03
7	End For

Table 10. Consequent Coefficients for Experiments

Parameters	**λ**	**u**	**v**	p_0	q_0
Value	4×10^{-7}	1	1	88800	154.9

$\boldsymbol{\lambda}$ is selected to balance the order magnitude of the economic index and the environmental index. Furthermore, $\boldsymbol{q_0}$ indicates the average income from selling a single herd, that is, the average price of herds in the nation, which is attained through divided the total GDP of Kenya due to animal husbandry (12% out of 97.86 billion in 2020 [18], subtracted by the part contributed by chicken) by estimated total number of herds sold in 2020 (36021200 + 25345900 + 227408500 × 3/2 [19]; the three components indicate numbers of goat, sheep, and cattle in Kenya, 2020, among which goats and sheep are mostly 1 year old when sold, while cattle are 1 and a half, and that's where the multiplier "3/2" comes from).

5.3 Result Analysis

By changing parameters for different areas within Maasai Mara, the optimal managements are shown with respect to different areas.

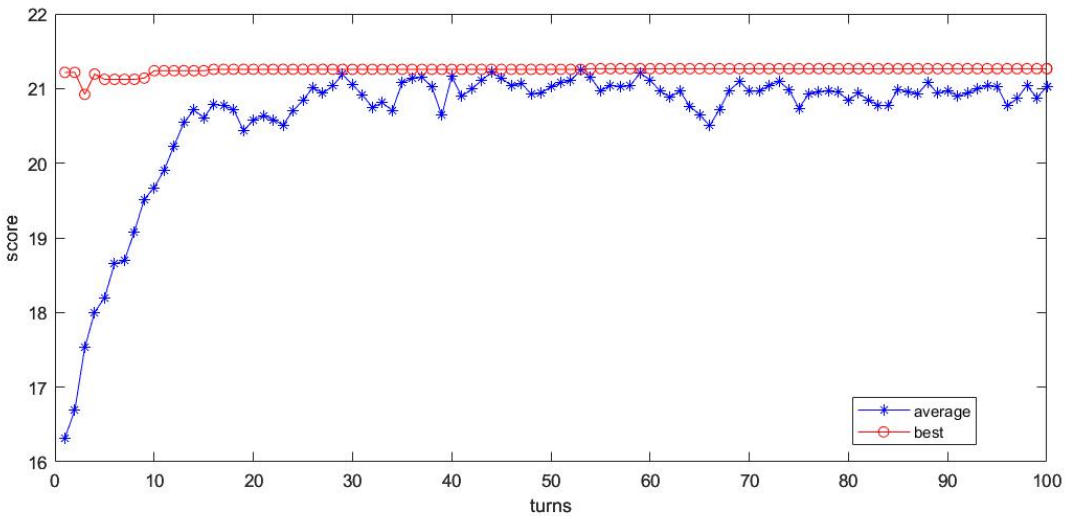

Figure 12. Process of Optimization with Genetic Algorithm

Table 11-19. Trials of Optimization

MMNR1	**1**	**2**	**3**	**4**
Aa	246.62	291.4	297.2	317.7
As	167.56	39.81	401.16	102.39
Ns	10314	9837	9788	9440
Score	**21.2070**	21.1974	21.1948	21.1874

MMNR2	**1**	**2**	**3**	**4**
Aa	144.28	219.04	190.73	268.88
As	220.92	166.63	266.37	166.47
Ns	8704	7654	8047	6917
Score	**21.0832**	21.0523	21.0639	21.0290

CSV1	**1**	**2**	**3**	**4**
Aa	64.22	121.13	115.31	97.99
As	191.22	59.04	34.11	58.37
Ns	4253	3450	3547	3750
Score	20.8287	**20.8520**	20.8086	20.8172

CSV2	**1**	**2**	**3**	**4**
Aa	30.56	58.51	89.77	66.15
As	32.02	44.57	12.4	51.81
Ns	4704	4259	3884	4171
Score	**20.8404**	20.8239	20.8138	20.8230

CSV3	**1**	**2**	**3**	**4**
Aa	153.28	298.15	270.66	151.96
As	145.09	5.92	19.52	128.59
Ns	2962	995	1374	2999
Score	20.8279	20.7600	20.7740	**20.8318**

CSV4	**1**	**2**	**3**	**4**
Aa	31.24	67.88	124.54	73.37
As	312.06	228.04	144.39	174.82
Ns	4668	4147	3378	4123
Score	**20.8890**	20.8689	20.8365	20.8650

TM1	**1**	**2**	**3**	**4**
Aa	254.65	330.22	268.16	252.86
As	81.99	55.57	95.71	81.26
Ns	5657	4588	5429	5699

Score	**21.0769**	21.0545	21.0740	21.0758

TM2	**1**	**2**	**3**	**4**
Aa	381.17	239.51	350.33	297.64
As	10.98	163.02	40.96	40.37
Ns	543	2606	937	1672
Score	20.8217	20.8286	20.7788	**20.8451**

TM3	1	2	3	4
Aa	79.34	98.95	102.31	101.88
As	2.74	36.99	10.26	24.39
Ns	915	630	578	552
Score	20.6723	20.6808	**20.6827**	20.5787

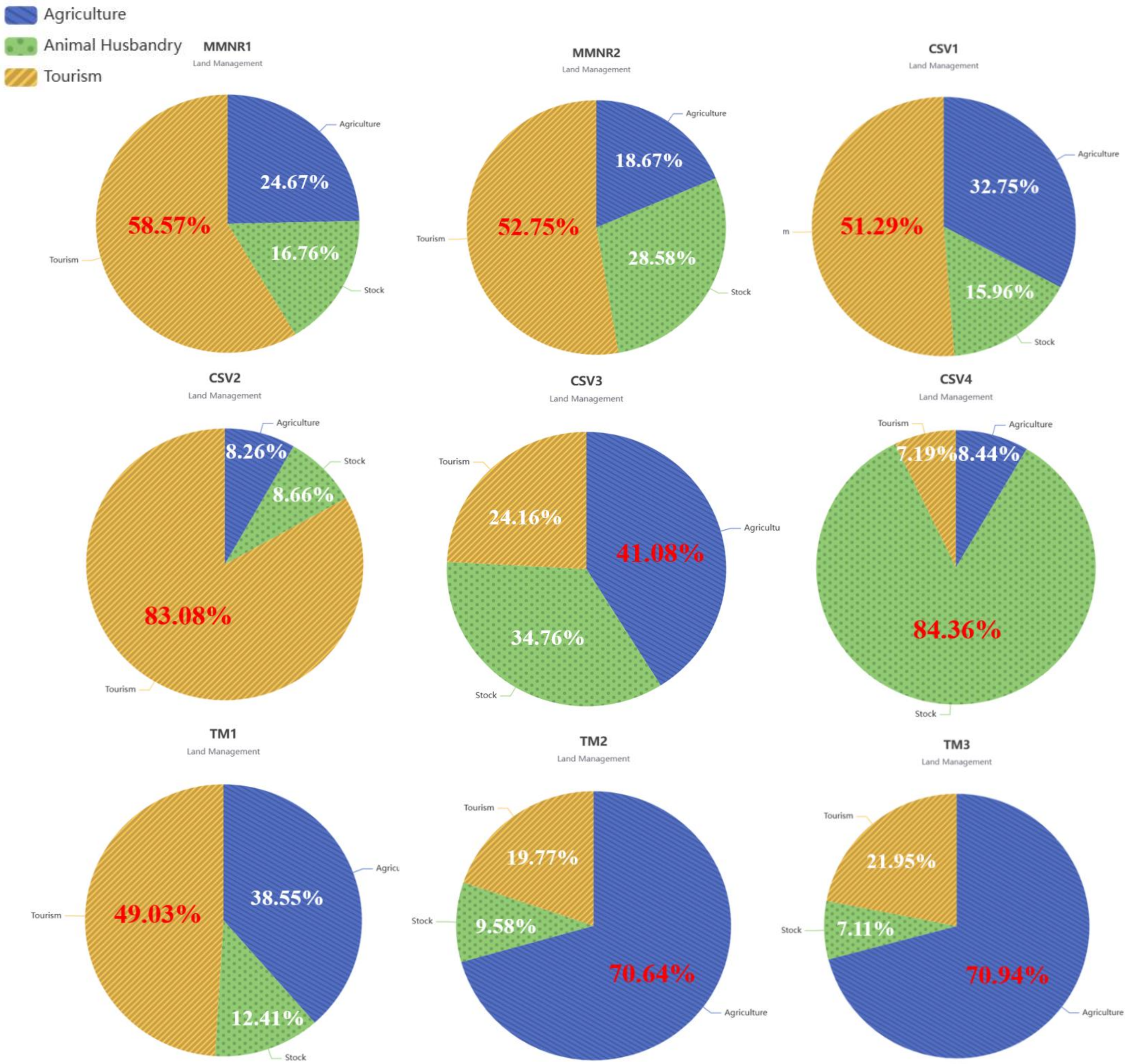

Figure 13. Strategies as Results (1)

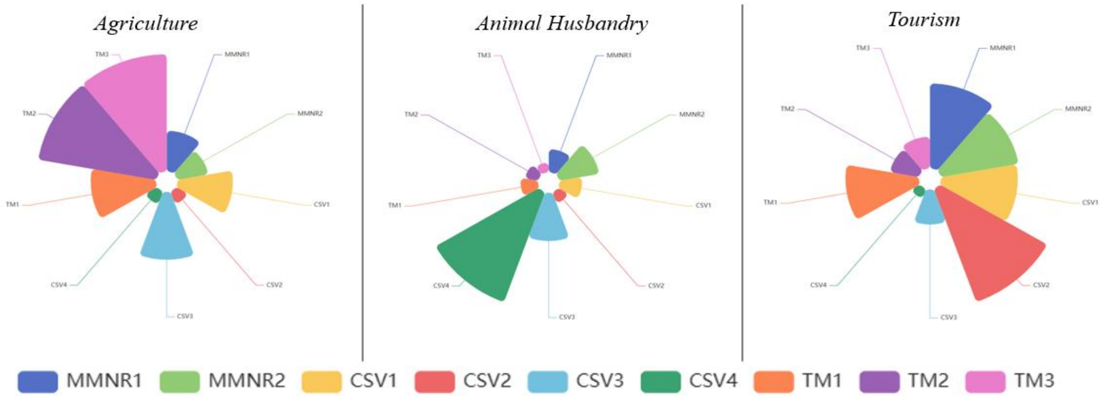

Figure 14. Strategies as Results (2)

From the pie charts, we can see that for subregions that are close to Maasai Mara National Reserve, i.e., MMNR1, MMNR2, CSV1, CSV2, TM1, they can all benefit a lot by distributing most of their land for tourists' accommodations. For subregion TM2 & 3, since they all have solid experience in farming and has a high farming efficiency, a large proportion of land distributed for farming is consistent with deduction. For subregion CSV3 & CSV4, since they are far from National Park, their conflicts with wildlife will be reduced, so a large proportion of land distributed for animal husbandry makes the optimal profit.

6. Evaluation of Model and Methodology

6.1 Long-term Prediction

Given our proposal, Maasai Mara will have a greater development in the future.

First, economically, from the Pie Chart and Nightingale Chart, it can be told that a clear recommendation of land distribution between agriculture, animal husbandry, and tourism. In the long run, the subregions near National Reserve, i.e., MMNR1, MMNR2, CSV1, CSV2, and TM1, will mainly develop tourism. But as we suggested, there will be a trend that tourism center moving towards CSV2, which will make space for agriculture development in TM1. Since α is calculated high in TM1 than CSV2, assume that finally agriculture will occupy 70.8% of its land just like TM2 and TM3, such transition will make a more profit of $\mathbf{26712871.4}$ dollars per year:

$$\$88800/km^2 \times 1.41 \times 660.52km^2 \times (70.8\% - 38.55\%) = \$26712871.4$$

Similarly, the Animal Husbandry is suggested to move toward CSV4 by us. In the long run, the conflict between wildlife and stock will be reduced since they will gather at different regions, i.e., MMNR2 and CSV4, which will also create more profit in animal husbandry.

Second, from perspective of be eco-friendly, since our optimization model takes wildlife density into account, the final optimal score also shows a good protection on wild animals. In this way, the grasslands are predicted to be more nutritious, and the landscape will be more attractive to tourists. According to our tourist prediction model, approximately 30~40% of increase on tourist quantity can be foreseen, which is about **7066800** dollars more government income by tickets selling in 2023 and even more in further future.

To be more specific, we propose that in the next ten years, more tourism facilities will be built around CSV2, so that it can accept more tourists to fit in the trend of increasingly more tourists. TM1 will progressively distributing more land to develop agriculture since its farming economic efficiency is high by our computation. Animal husbandry will transit to gather at CSV4, which can reduce conflict between stock and wildlife.

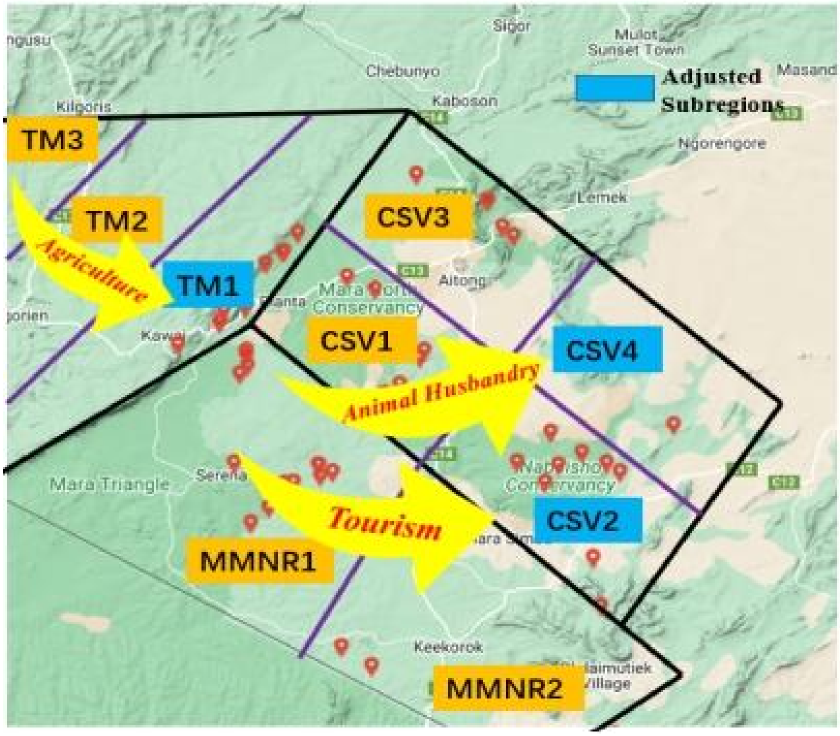

Figure 15. Industrial Modification Based on Our Result

6.2 Discussion of Methodology

While attempting to apply our methodology to other wildlife managements, several details are supposed to be noted.

Firstly, our tourist quantity prediction model is refined to fit the current situation. Since the world is still under influence of the pandemic, a process of sharp declination and recovery is necessary. Our model provides a new method which is suitable in a wider range, making a better prediction under pressure of pandemic.

Secondly, our objective function takes both economy factor and ecosystem factor into account, which helps development of reserves be more sustainable. By a measure and statistics upon the region, the parameters in the model can be adjusted to fit in different kinds of regions. Specifically, the adjustment of λ, u, v can help achieve different ratios of balance between economy and ecosystem, the adjustment of α according to the method we provide in section 3.1.2 can fine tune the model to different climates. What's worth minding is that due to the probably different climate and form of organization for agricultural production near other natural reserves, the linear association between α and simply rainfall would be likely to no longer maintain its validity. New non-linear estimation for the relation will be necessary.

Thirdly, our policy and strategy optimization model mainly focus on the adjustment among agriculture, animal husbandry, and tourism, most of which are known common in most of the reserves, since strategies are usually the most important issue to consider. There are few characteristic policies relying on unique features of Maasai Mara, so most other reserves are supposed to be able to smoothly imitate our example of Maasai Mara in order to achieve their own goals.

6.3 Future work

A more detailed separate analysis that minding species of wildlife and livestock may be helpful to further optimize our interaction model between human and wildlife. Moreover, taking the influence of animal migration on agriculture, animal husbandry, and tourism into consideration when optimizing the distribution of them can also be a promising researching area.

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Report: Reshaping the Maasai Mara

1.Introduction

Agriculture

Husbandary

When it comes to balancing the interests between human and wildlife in Maasai Mara, people always focus their attention on specific strategies like fencing, prohibiting poaching etc. Although undeniably some of them are effective methods to help mitigate the conflict between people and wildlife, it's difficult and of little importance to evaluate them mainly owing to their different purposes as well as singular characteristic.Hence, it's necessary to shift our perspective from micro to macro.

In Mara, the land has three main purposes, agriculture, husbandry, and reserve (green tourism). Obviously, by changing the proportion of different industries, we can attain different outcomes. For example, when the area of the reserve becomes bigger, the environmental protection will become better at the expense of economic benefits.

Therefore, we think it enlightening to reshape the Maasai Mara region by adjusting the allocation of land use, thus reaching the best economic profits as well as environmental-protection effectiveness.

2.Proposed Plan and its value

We set the region into nine parts, MMNR1, MMNR2, CSV1, CSV2, CSV3, CSV4, TM1, TM2, TM3.

Our study finds that, the agriculture industry in TM3 should shift gradually to TM1, the tourism in MMNR1 to CSV2, and Animal Husbandry to CSV4.

Under this allocation plan, the wildlife density will become greater, indicating the protection of environment is effective. And in the mean time, the economic profits also become bigger.

With greater economic profits, government can invest more money on public welfare like health and education. And in the mean time, local people there can enjoy a more harmonious relationship between the wildlife since they don't need to poach or graze illegally to earn their bread.

To conclude, our plan gives an innovative perspective into the human wildlife conflict and in the future will yield more accurate plan and ultimately reshape the Maasai Mara.