Problem Chosen	2026 MCM/ICM Summary Sheet	Team Control Number
B		2615409

Here is Your Title

Summary

Introduction of the background and the mission we accomplished.

Global warming, El Niño... With the emergence of various extreme climates,**Australia's wildfires** occur more frequently. The greenhouse gases emitted after combustion have exacerbated global warming, which seems to have entered an endless loop. At the same time, hundreds of millions of lives have been killed in the fire, which makes us sad. To better control wildfires, we modeled the **distribution of drones** assisting in the observation to achieve the best balance between economy and efficiency.

This is our models.

Several models are established: Model I: Rasterized Multi-Objective Optimization Model; Model II: Model Verification Simulated by Poisson Process; Model III: Hovering Model Based on Tabu Search, etc.

For Model I: Firstly,We find data。。。Then,we establish **model**。。。Next,we use Algorithm。。。Finally,it can be seen that。。。

For Model II: Firstly,We find data。。。Then,we establish model。。。Next,we use Algorithm。。。Finally,it can be seen that。。。

For Model III: Firstly,We find data。。。Then,we establish model。。。Next,we use Algorithm。。。Finally,it can be seen that。。。

Finally, sensitivity analysis 。。。Meanwhile, robustness

Keywords: MATLAB, mathematics, LaTeX.

Contents

1 Introduction

1.1 Problem Background

Some people envision a Space Elevator System, powered by electricity, offering a scalable infrastructure for interplanetary logistics, commerce, and exploration.

At its final operating configuration, the Space Elevator System would comprise three Galactic Harbours, ideally separated by 120 degrees around the equator. Each Galactic Harbour would include a single Earth port with two100,000 km-long tethers connected to two apex anchors, with multiple space elevators operating together, each capable of lifting massive payloads daily from Earth to geosynchronous orbit (GEO) and beyond to the apex anchor where they can be loaded on a rocket and delivered anywhere using much less fuel.

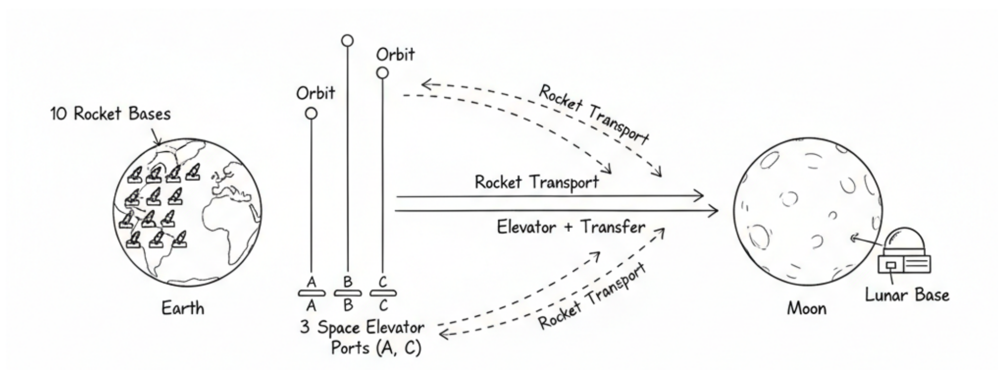

Figure 1: problem background

Based on the plan above,The Moon Colony Management (MCM) Agency is preparing to build a Moon Colony with an estimated 100,000 people beginning in the year 2050, after completion of the Space Elevator System.

The agency is also considering using traditional rockets to supply material for construction and supplies to the Moon Colony. The Earth current has ten rocket launch sites: Alaska, California, Texas, Florida, and Virginia (United States), Kazakhstan, French Guiana, Satish Dhawan Space Centre (India), Taiyuan Satellite Launch Center (China), and Mahia Peninsula (New Zealand).

As shown in figure1,the schematic of the Space Elevator System and Moon Colony is illustrated above.

1.2 Literature Review

Three major problems are discussed in this paper, which are:

- First and foremost, it is necessary to analyze three distinct scenarios for delivering the 100 million metric tons of materials required for the construction of the 100,000-person Moon Colony. The three scenarios to be considered include: (a) relying solely on the three Galactic Harbors of the Space Elevator System for material delivery; (b) relying exclusively on traditional rocket launches from selected existing space facilities (with the flexibility to choose specific launch bases); and (c) adopting a hybrid delivery strategy that combines the Space Elevator System's Galactic Harbors and traditional rocket launches. For each scenario, a comprehensive assessment of the material delivery feasibility, efficiency, and rationality must be conducted.
- Second, the robustness of the proposed material delivery solutions needs to be evaluated under the condition that transportation systems are not in perfect working order. Potential anomalies may include, but are not limited to, tether swaying of the Space Elevator System, rocket launch failures, and elevator malfunctions. It is required to analyze the extent to which such operational imperfections would alter the previously proposed delivery strategies and how the solutions should be adjusted to maintain the feasibility of material delivery.
- Third, the water demand of the 100,000-person Moon Colony over a one-year period after it is fully operational must be systematically investigated. Based on the established material delivery model (from the first research task), the additional costs and extended timeline required to ensure the colony has sufficient water supply for one full year after its inhabitation should be quantified and analyzed, thereby supplementing the delivery model with water supply-related constraints and considerations.
- Finally, the environmental impacts on Earth associated with achieving the 100,000-person Moon Colony under each of the three material delivery scenarios must be discussed in depth. On this basis, corresponding adjustments to the established delivery model should be proposed to minimize the adverse environmental impacts on Earth while ensuring the successful construction and operation of the Moon Colony.

A literatrue[?] reviews the water demand of lunar bases: the basic domestic water consumption is 4.17 kg per person per day, covering drinking, sanitation and other uses. A daily wastewater yield of 5.57 kg per person is generated, with condensed water and urinary wastewater recoverable as supplementary water sources. The base is designed with 167 kg of emergency water storage for a 10-day evacuation window, with low reliability requirements for water supply systems. Cost and reliability can be balanced via redundancy design or three-loop systems, and the relevant water system technologies are adaptable to the gravitational environments of the Moon and Mars (data based on NASA Exploration Program assumptions).

A literature[?] confirm that space elevators have a solid technological and economic feasibility basis. High-strength materials such as carbon nanotubes meet the theoretical strength requirements; Low Earth Orbit (LEO) space elevators are technologically feasible with supporting propulsion solutions. Mature space infrastructure and resource exploitation underpin economic viability. The equator is the optimal location, and space debris removal is a critical safety priority. Space elevators can drastically cut orbital access costs and boost space industrial development. Their realization relies on material breakthroughs, phased verification and global cooperation, with projection for implementation in the late 21st century.

A literatrue[?]shows:Rocket exhaust produces positive radiative forcing (RF), primarily due to black carbon (BC) and alumina particles. Carbon dioxide (CO) emissions from rockets contribute negligibly to RF compared to particulate emissions. Current global RF from rocket launches is estimated at 16 ś 8 mW mš, with BC accounting for 70 percents of this value.

1.3 Our work

We do such things ... 这部分直接上图

1. We do ...

2. We do ...

3. We do ...

2 Preparation of the Models

2.1 Assumptions and Explanations

To simplify the problem, we made the following assumptions, each of which has a corresponding reasonable explanation.

- ***Assumption 1:*** 物资分级连续性：分为关键物资（优先 SE 运输）和普通物资，均视为准连续流体。
  ↪ ***Explanation:*** 工程中物资存在优先级，SE 高可靠性适配关键物资，符合调度逻辑。
- ***Assumption 2:***$\alpha(t)$ 为分段常数函数：将总工期划分为 50 个时间区间（每区间 1-2 年），每个区间 α_i 为常数。
  ↪ ***Explanation:*** 平衡计算精度与效率，适配 MCM 竞赛求解需求，易实现且结果直观。
- ***Assumption 3:*** 水资源消耗：人均日用水量 0.15 吨，年人均 54.75 吨，循环效率 $\gamma = 0.85$。
  ↪ ***Explanation:*** 参考国际空间站用水标准，循环效率符合 2050 年技术水平预测。
- ***Assumption 4:*** 非完美状态参数：SE 缆绳摆动临界角 5ř，年故障概率基准值 2%；TR 发射失败概率 3%，发射窗口关闭导致运力折损 30%。
  ↪ ***Explanation:*** 基于航天工程历史数据与题目场景合理设定。
- ***Assumption 5:*** 成本参数：SE 固定成本 1000 亿美元，单位可变成本 1000 美元/吨；TR 单次发射成本 1 亿美元。
  ↪ ***Explanation:*** 参考 Falcon Heavy 当前成本与未来技术迭代趋势，量级合理。
- ***Assumption 6:*** 顶端火箭发射失败时成本不计。
  ↪ ***Explanation:*** 由于顶端火箭载荷量未知，成本波动计入原成本内。
- ***Assumption 7:*** 月球人均用水量近似为地球人均用水量。
  ↪ ***Explanation:*** 简化问题，方便计算。
- ***Assumption 8:*** 原有的火箭发射中心启用时成本为零。
  ↪ ***Explanation:*** 现有发射场启用时不应有成本。

Additional assumptions are made to simplify analysis for individual sections. These assumptions will be discussed at the appropriate locations.

2.2 Notations

Table 1 lists some important mathematical notations used in this paper.

Table 1: Notations used in this paper

Symbol	Description
α_i	第 i 个时间区间的 SE 运输比例（$\alpha(t)$ 分段常数）
q_i	第 i 个时间区间的平均运力
I_{safe}	安全冗余系数
M_{tot}	建设物资总量
$\kappa_{SE,total}$	SE 系统总年运力
m_{load}	TR 单次 payload 基准值
$f_{TR}(j)$	第 j 个 TR 发射场年最大发射频次
C_{fix}^{SE}	SE 系统总固定成本
c_{var}^{SE}	SE 单位可变成本 + 顶端火箭单位质量发射成本
c_{launch}	TR 单次发射成本
P_{pop}	月球殖民地人口
w_{per}	人均日用水量
γ	水资源循环效率
$Q_{SE}(i)$	前 i 个区间 SE 累积运输量
$Q_{TR}(i)$	前 i 个区间 TR 累积运输量
$D(i)$	第 i 个区间 SE 累积损坏因子
$\kappa'_{SE}(i)$	第 i 个区间 SE 有效运力（非完美状态）
$\kappa'_{TR}(i)$	第 i 个区间 TR 有效运力（非完美状态）
f_{cost}	全生命周期总成本
f_{time}	总工期
f_{env}	综合环境影响指数

*Some variables are not listed here and will be discussed in detail in each section.

2.3 Data

2.3.1 Data Collection

Websites, where we collect data, are listed in Table 2.

Table 2: Notations used in this paper

Database Names	Database Websites
Google Scholar	https://scholar.google.com
Wikipedia	https://www.wikipedia.org
wolframalpha	https://www.wolframalpha.com

3 Model 1: 静态基准模型

3.1 模型概述

静态基准模型在完美工作状态下分析三种运输场景，为比较不同物资运输方案的可行性、经济性和工期提供基础。

3.2 场景一：仅 SE 模式

3.2.1 完美状态运力

太空电梯系统的年运输能力为：

$$\kappa_{SE,total} = 179,000 \text{ 吨/年} \tag{1}$$

3.2.2 项目工期

物资全部运输所需的总工期为：

$$T_{SE} = \frac{M_{tot}}{\kappa_{SE,total}} = \frac{1 \times 10^8}{179000} \approx 558.7 \text{ 年} \tag{2}$$

3.2.3 总成本

全生命周期成本包括固定基础设施成本和可变运营成本：

$$C_{SE} = C_{fix}^{SE} + M_{tot} \cdot c_{var}^{SE} \tag{3}$$

其中 C_{fix}^{SE} 为太空电梯系统的总固定成本，c_{var}^{SE} 为单位可变成本（美元/吨）。

3.3 场景二：仅 TR 模式

3.3.1 完美状态运力

启用全球 10 个发射场时，传统火箭系统的年运输能力为：

$$\kappa_{TR} = 10 \cdot f_{TR}(j) \cdot m_{load} = 10 \times 20 \times 125 = 25,000 \text{ 吨/年} \tag{4}$$

其中 $f_{TR}(j)$ 为单个发射场年最大发射频次（20 次/年），m_{load} 为单次发射的基准载荷（150 吨）。

3.3.2 项目工期

物资全部运输所需的总工期为：

$$T_{TR} = \frac{M_{tot}}{\kappa_{TR}} = \frac{1 \times 10^8}{25000} = 4000 \text{ 年} \tag{5}$$

3.3.3 总成本

成本由所需发射次数决定：

$$C_{TR} = \frac{M_{tot}}{m_{load}} \cdot c_{launch} \tag{6}$$

其中 c_{launch} 为单次发射成本（美元/次）。

3.4 场景三：混合静态模式

混合策略结合太空电梯和传统火箭两种运输方式，以优化项目工期和成本。

3.4.1 项目工期

混合运输的工期由两种运输方式中耗时较长的决定：

$$T_C(\alpha) = \max\left(\frac{\alpha M_{tot}}{\kappa_{SE,total}}, \frac{(1-\alpha) M_{tot}}{\kappa_{TR}}\right) \tag{7}$$

3.4.2 最优分配比例

从工期角度考虑，最优分配比例 α^* 满足两种运输方式的完成时间相等：

$$\frac{\alpha^* M_{tot}}{\kappa_{SE,total}} = \frac{(1-\alpha^*)M_{tot}}{\kappa_{TR}} \tag{8}$$

解得最优分配比例：

$$\alpha^* = \frac{\kappa_{SE,total}}{\kappa_{SE,total} + \kappa_{TR}} = \frac{179000}{179000 + 25000} \approx 0.417 \tag{9}$$

3.4.3 总成本

混合策略的全生命周期成本为：

$$C_C = \frac{(1-\alpha)M_{tot}}{m_{load}} \cdot c_{launch} + C_{fix}^{SE} + \alpha M_{tot} \cdot c_{var}^{SE} \tag{10}$$

该成本包括太空电梯固定基础设施成本（一次性）、太空电梯运营可变成本和传统火箭发射成本。

3.5 三种场景的比较分析

静态基准模型提供以下重要洞察：

- **仅 SE 模式：**需约 558.7 年完成物资运输，一旦基础设施建成后，运营成本最低。
- **仅 TR 模式：**需约 4000 年完成物资运输，在项目工期和成本约束下经济上不可行。
- **混合最优模式（$\alpha^* \approx 0.417$）：**采用最优分配比例，工期约为 $\max\left(\frac{0.417\times10^8}{179000}, \frac{0.583\times10^8}{25000}\right) \approx$ 232 年，在基础设施固定成本和按次发射成本间实现平衡。
- **决策选择：**三种方案的优劣取决于对工期最小化或成本最小化的优先级权重。

4 Model 2: 动态扩展模型（时间自适应策略）

4.1 动态调整逻辑

随着时间的推移和技术的发展，太空电梯系统的单位可变成本 c_{var}^{SE} 逐渐下降。采用如下理想化模型表示这一过程：

$$c_{var}^{SE} = 0.8c_0 + 0.2c_0 \exp(-0.0139i) \tag{11}$$

其中 c_0 为初始成本，25 个时间区间后成本降至原值的 0.9 倍。

运输分配比例 $\alpha(t)$ 由太空电梯和传统火箭系统的瞬时单位成本比 $\rho(t)$ 驱动：

$$\rho(t) = \frac{c_{var}^{SE}(t, Q_{SE}(t))}{c_{TR}(t, Q_{TR}(t))} \tag{12}$$

根据成本比的大小，对 α_i 的决策规则为：

- 当 $\rho(t) < 0.8$（SE 更便宜）时：$\alpha_i = 1$
- 当 $\rho(t) > 1.2$（TR 更便宜）时：$\alpha_i = 0$
- 当 $0.8 \leq \rho(t) \leq 1.2$（成本均衡）时：$\alpha_i \in (0, 1)$，为重点优化方向，目标是最小化区间内的成本和环境影响

4.2 动态目标函数

4.2.1 目标 1：总项目工期

总工期是使累积运输量达到要求的最小时间区间数：

$$T = \min \left\{ k \cdot \Delta t \mid \sum_{i=1}^{k} q_i \geq M_{tot} \right\} \tag{13}$$

其中累积运输量递推关系为：

$$Q_{SE}(i) = Q_{SE}(i-1) + \alpha_i \cdot q(i) \cdot \Delta t \tag{14}$$

$$Q_{TR}(i) = Q_{TR}(i-1) + (1-\alpha_i) \cdot q(i) \cdot \Delta t \tag{15}$$

时间区间长度 $\Delta t = 5$ 年，可根据需要调整。

4.2.2 目标 2：全生命周期成本（分段求和）

全生命周期总成本为：

$$f_{cost} = \mathbb{I}\left(\sum_{i=1}^{k} \alpha_i > 0\right) \cdot C_{fix}^{SE} + \sum_{i=1}^{k} \left[q_{SE}(i) \cdot c_{var}^{SE}(i) + q_{TR}(i) \cdot c_{TR}(i)\right] \cdot \Delta t \tag{16}$$

其中：

$$c_{TR}(i) = \frac{c_{launch}}{m_{load}} \tag{17}$$

指示函数 $\mathbb{I}$ 确保太空电梯固定成本仅在使用太空电梯时计入一次。

4.3 动态约束条件

优化问题受以下约束条件限制：

$$\begin{cases} 0 \leq \alpha_i \leq 1, \quad \forall i = 1, 2, \ldots, 50 \\ \alpha_i \cdot q(i) \leq \kappa'_{SE}(i), \quad \forall i \\ (1 - \alpha_i) \cdot q(i) \leq \kappa'_{TR}(i), \quad \forall i \\ Q_{SE}(50) + Q_{TR}(50) \geq M_{tot} \end{cases} \tag{18}$$

约束条件的含义分别为：

- 分配比例 α_i 必须在有效范围内
- 每个时间区间太空电梯的运输量不能超过其有效运力 $\kappa'_{SE}(i)$
- 每个时间区间传统火箭系统的运输量不能超过其有效运力 $\kappa'_{TR}(i)$
- 第 50 个区间结束时，累积运输总量必须达到所需的全部物资

4.4 模型特点

动态 $\alpha(t)$ 扩展模型相比静态基准模型的主要优势为：

1. **时间自适应**：根据技术发展动态调整运输方式比例，充分利用成本下降机遇
2. **成本优化**：通过实时比较两种运输方式的单位成本，在成本均衡区间内进行精细优化
3. **分段规划**：将总工期划分为 50 个区间，每个区间独立决策，便于实施和调整
4. **多目标平衡**：同时考虑工期、成本和环境影响，寻求综合最优方案

5 Model 3: 随机扰动的修正模型

5.1 火箭发射失败的修正

5.1.1 失败概率与有效载荷

传统火箭系统存在发射失败的风险。引入发射失败概率 P_{fail}，有效载荷的期望值为：

$$E[m] = m_{\text{load}} \cdot (1 - P_{\text{fail}}) \tag{19}$$

5.1.2 发射成本调整

考虑失败风险导致的成本增加：

$$c'_{\text{launch}} = c_{\text{launch}} + P_{\text{fail}} \cdot (c_{\text{launch}} + c_{\text{cargo\_loss}}) \tag{20}$$

其中 $c_{\text{cargo\_loss}}$ 为货物损失成本。

5.1.3 修正运力

火箭系统的实际运力上限应为：

$$\kappa'_{TR}(i) = \kappa_{TR} \cdot (1 - P_{\text{fail}}(i)) \tag{21}$$

其中 $P_{\text{fail}}(i)$ 可以是固定值，也可随时间或发射条件变化。

5.1.4 修正成本公式

成本公式中，传统火箭的单位成本应修改为：

$$c_{TR}(i) = c_{\text{launch}} + P_{\text{fail}}(i) \cdot (c_{\text{launch}} + c_{\text{cargo\_loss}}) \tag{22}$$

这样将发射失败的风险成本纳入总成本计算。

5.2 系绳摇晃的科里奥利力与风切变扰动

5.2.1 瞬时可用度函数

太空电梯系统的可用性受摆动幅度和风速的影响。定义瞬时可用度函数为：

$$\eta_{SE}(t) = \begin{cases} 1, & \text{if } \theta(t) < \theta_{\text{crit}} \text{ and } W_{\text{wind}}(t) < v_{\text{safe}} \\ 0, & \text{otherwise} \end{cases} \tag{23}$$

其中 $\theta(t)$ 为系绳摆动角度，θ_{crit} 为临界摆动角度（$5°$）；$W_{\text{wind}}(t)$ 为风速，v_{safe} 为安全风速限制。风场满足韦布尔分布。

5.2.2 顶端火箭发射失败概率

由于太空电梯顶端仍需火箭发射将货物送入轨道，存在失败概率 P'_{fail}。

5.2.3 修正后的年有效运力

综合考虑摆动限制、维护停机和火箭发射失败，太空电梯的修正后年有效运力为：

$$\kappa'_{SE} = \kappa_{SE} \cdot \frac{1}{T_{\text{year}}} \int_0^{T_{\text{year}}} \eta_{SE}(t)\, dt \cdot (1 - \beta_{\text{maint}}) \cdot (1 - P_{\text{fail}'}) \tag{24}$$

其中：

- T_{year} 为一年时长
- $\frac{1}{T_{\text{year}}} \int_0^{T_{\text{year}}} \eta_{SE}(t)\, dt$ 为年可用度因子
- β_{maint} 为维护停机系数
- $(1 - P_{\text{fail}'})$ 为火箭发射成功率

5.3 一年用水需求下的运输成本

5.3.1 月球殖民地年净用水需求

月球殖民地一年的净用水需求（考虑水资源循环）为：

$$M_{net} = M_{gross} \cdot (1 - \gamma) = 365 P_{pop} \cdot w_{per} \cdot (1 - \gamma) \tag{25}$$

其中：

- M_{gross} 为年总用水量
- $\gamma = 0.85$ 为水资源循环效率
- $P_{pop} = 10$ 万人为月球殖民地人口
- $w_{per} = 0.15$ 吨/(人 · 天) 为人均日用水量

5.3.2 额外运输成本

一年的净用水需求所产生的额外运输成本取决于选用的运输方式。对于仅使用太空电梯的情况：

$$C_{water,SE} = M_{net} \cdot c_{var}^{SE} \tag{26}$$

对于仅使用传统火箭的情况：

$$C_{water,TR} = \frac{M_{net}}{m_{load}} \cdot c_{launch} \tag{27}$$

对于混合策略，需根据动态模型中的最优分配比例 α 计算。

6 Test the Model

6.1 Sensitivity Analysis

6.2 Robustness Analysis

这部分很重要，不能缺！

7 Conclusion

7.1 Summary of Results

7.2 Strengths

- The sensitivity analysis of the model demonstrates the effectiveness of the model under different parameter combinations and prove the robustness of the mod
- Second one ...

7.3 Weaknesses and Improvements

- The analysis of fish migration can be more accurate if we have more complete data;
- Some approximate analysis methods are applied to model the management of fishing companies, which may lead to a situation contrary to the actual one in extreme cases.
- 此处引用了 LLM.[2]

Memorandum

To: Heishan Yan
From: Team 1234567
Date: October 1st, 2019
Subject: A better choice than MS Word: LaTeX

In the memo, we want to introduce you to an alternate typesetting program to the prevailing MS Word: **LaTeX**. In fact, the history of LaTeX is even longer than that of MS Word. In the 1970s, the famous computer scientist Donald Knuth first came out with a typesetting program, named TeX ...

Firstly, ...

Secondly, ...

Lastly, ...

According to all those mentioned above, it is really worth to have a try on LaTeX!

References

[1] Helmut Kopka and Patrick W Daly. *Guide to LATEX*. Pearson Education, 2003.

[2] OpenAI. Chatgpt: Optimizing language models for dialogue, Feb 2024. Available online: `https://openai.com/chatgpt` (accessed on February 2^{nd}, 2024).

Appendix A: Further on LaTeX

To clarify the importance of using LaTeX in MCM or ICM, several points need to be covered, which are ...

To be more specific, ...

All in all, ...

Anyway, nobody **really** needs such appendix ...

Appendix B: Program Codes

Here are the program codes we used in our research.

code/example.py

```
# Python code example
for i in range(10):
    print('Hello,␣world!')
```

code/example.m

```
% MATLAB code example
for i = 1:10
    disp("hello, world!");
end
```

Appendix C: Report on Use of AI

1. OpenAI ChatGPT (Nov 5, 2023 version, ChatGPT-4)

Query1: <insert the exact wording you input into the AI tool>

Output: <insert the complete output from the AI tool>

2. OpenAI Ernie (Nov 5, 2023 version, Ernie 4.0)

Query1: <insert the exact wording of any subsequent input into the AI tool>

Output: <insert the complete output from the second query>

3. Github CoPilot (Feb 3, 2024 version)

Query1: <insert the exact wording you input into the AI tool>

Output: <insert the complete output from the AI tool>

4. Google Bard (Feb 2, 2024 version)

Query: <insert the exact wording of your query>

Output: <insert the complete output from the AI tool>