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Forecasting the technological development of the falcon launch vehicles using a mathematical modeling approach

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Abstract: The rapid advancement of private aerospace initiatives has intensified the need for strategic forecasting of launch vehicle technologies. This study presents a mathematical projection of the technological evolution of SpaceX's Falcon 9 and Falcon Heavy rockets over the period 2025–2030. In light of increasing global reliance on reusable launch systems, the research addresses the current gap in quantitative forecasting models tailored to specific vehicle platforms. Five critical factors were identified: reusability technology, financial investment, volume of scientific research, technical innovation index, and expert assessments. Each variable is modeled using appropriate mathematical functions, and their relative influence is weighted based on literature review and expert judgment. The resulting compound model calculates annual technological advancement scores for both launch systems. Additionally, the study evaluates the economic efficiency of these developments and explores their potential implications for emerging space programs in developing countries, particularly Uzbekistan. The findings offer valuable insights for policymakers, engineers, and investors aiming to optimize long-term strategic planning in the rapidly evolving space industry.
Keywords: Falcon 9, Falcon Heavy, Forecasting, Mathematical modeling, Reusable launch systems, Economic efficiency

1. Introduction

The 21st century has witnessed a paradigm shift in the global space industry, driven by the growing involvement of private aerospace enterprises. Among these, SpaceX (Space Exploration Technologies Corp.), established by Elon Musk in 2002, has emerged as a pioneering force in space transportation and reusable launch systems. SpaceX has revolutionized the launch vehicle sector through innovative designs and cost-effective solutions, particularly with its Falcon series of rockets.[1].

The Falcon 9, first launched in 2010, is a partially reusable two-stage rocket developed to transport cargo and crew to low Earth orbit (LEO), as well as to deliver payloads to various other orbits. Its larger counterpart, the Falcon Heavy, introduced in 2018, incorporates three Falcon 9 first-stage boosters and is currently the most powerful operational rocket globally in terms of payload-to-orbit capability. These rockets represent a breakthrough in reusability technology, which significantly reduces launch costs and turnaround time, enabling more frequent missions and greater access to space.[2],[3].

In recent years, the continued refinement of propulsion systems, guidance software, launch logistics, and payload integration has positioned the Falcon launch systems as central assets in both commercial and governmental space missions. With the growing demands for satellite deployment, space station resupply, and even crewed missions, the future trajectory of these systems requires accurate forecasting to inform both engineering strategies and investment decisions.

This research focuses on the forecasting of technological development for the Falcon 9 and Falcon Heavy launch vehicles over the period 2025 to 2030. A mathematical model was constructed based on multiple influencing factors, including reusability maturity, financial investment, research activity, technical innovation index, and expert assessments. These factors were quantified and analyzed to project the future technological performance of each rocket variant. The model also considers empirical data and uses weighted indicators to evaluate the progression over time.[4],[5].

In addition to the technological projection, this study examines the economic efficiency of Falcon rockets, analyzing cost-per-launch reductions, mission frequency growth, and overall industry impact. The research also assesses how such launch systems could be utilized or adapted within the context of Uzbekistan's emerging space infrastructure, offering national-level insights and recommendations.[6],[7].

Ultimately, the study contributes to the broader discourse on sustainable space launch technologies, providing a replicable methodology for other launch systems and highlighting SpaceX's role in shaping the future of orbital access.

2. Research methodology

The primary objective of this study is to forecast the technological advancement levels of Falcon 9 and Falcon Heavy launch vehicles over the period from 2025 to 2030 through mathematical modeling. The employed model falls under the category of a multi-factor empirical weighted mathematical model. It exhibits a deterministic nature and incorporates semi-linear characteristics, combining both logarithmic and linear elements. The methodological approach involves time-dependent analysis of each contributing factor, weighted according to its significance, to calculate the overall trajectory of technological development.[8].

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Table 1

Description and mathematical expression of indicators

№	Description of Indicator	Mathematical Expression	Weight Coefficient
1	Technological potential of reusability	$f_1(t)=\ln t - y_0 + 1$	0.25
2	Scale of financial investments (log-scaled)	$f_2(t)=\ln(F(t))$	0.15
3	Rate of research publications and patents	$f_3(t=R(t)$	0.20
4	Innovation progression index	$f_4(t)=1+0.05\cdot(t-2025)$	0.20
5	Evaluations given by expert professionals	$f_5(t)=E(t)$	0.20

Clarification of Each Factor (Rewritten)

Technological Potential of Reusability. This parameter assesses the advancement stage of rocket reuse technology, reflecting how mature and economically viable reusability has become over time.

Scale of Financial Investments (log-scaled). It measures the amount of yearly investments allocated to development, modeled logarithmically to reflect diminishing marginal effects of capital input.

Rate of Research Publications and Patents. Represents the number of academic and technical outputs such as journal articles and intellectual property filings related to Falcon-class launch systems in a given year.

Innovation Progression Index. A factor estimating annual technological improvements, based on the assumption of a 5% annual increase in innovation performance after 2025.

Evaluations Given by Expert Professionals. Derived from domain experts' scores (on a 1–10 scale), this indicator reflects qualitative assessments of the rockets' technological status and potential.[9],[10].

Weight Justification for Analytical Factors

The weight coefficients for the selected indicators were determined based on expert evaluations and prior analytical studies in the field. The distribution rationale is as follows:

- Technological potential reusability (0.25) – As the key driving force behind innovation and cost-efficiency in launch systems, this factor is assigned the highest weight.
- Scale of financial investments (log-scaled) (0.15) – Although budget allocation is essential, it does not always directly translate to technological breakthroughs, thus receiving a slightly lower weight.
- Rate of research publications and patents (0.20) – The number of scientific publications and patents is closely correlated with innovation; hence, it holds high importance.
- Innovation progression index (0.20) – This factor reflects steady advancement in technology through regular upgrade cycles.
- Evaluations given by expert professionals (0.20) – Although based on subjective insights, expert assessments are valuable in forecasting the long-term technological potential.[11].

Explanation of Each Factor and Formula

Technological Potential of Reusability

$$f_1(t)=\ln t - y_0 + 1 \quad [1]$$

- t = year of evaluation.
- y_0 = base year when reusability was initiated.

This logarithmic model represents diminishing returns from maturing technologies.[12].

Scale of Financial Investments (log-scaled)

$$f_2(t)=\ln(F(t)) \quad [2]$$

- $F(t)$ = total capital allocated for development in year (t).

Logarithmic modeling captures saturation in investment impact.[13],[14].

Rate of Research Publications and Patents

$$f_3(t=R(t) \quad [3]$$

- $R(t)$ = number of publications or patents

Indicates growth of technological knowledge and innovation rate.

Innovation Progression Index

$$f_4(t)=1+0.05\cdot(t-2025) \quad [4]$$

Suggests 5% yearly incremental technical improvement based on a fixed 2025 baseline.

Evaluations Given by Expert Professionals

$$f_5(t)=E(t) \quad [5]$$

- $E(t)$ = average rating from aerospace experts (1–10 scale)

Final Composite Model

The technological progress index $T(t)$ is computed by aggregating weighted values of each factor:

$$T(t) = \sum_{i=1}^{n} \omega_I \cdot f_i(t) \quad [6]$$

Where:

- ω_i = assigned weight of factor i
- $f_i(t)$ = computed value of factor i at year t

This model enables year-by-year forecasting of the overall development trajectory of launch vehicle technology, based on transparent and justifiable indicators.[15].

Sample Factor Calculation for Falcon 9

For the year 2025, the reusability factor $\boldsymbol{f_1(t)}$ was calculated using the logarithmic growth function:

$$f_1(2025) = \ln 2025 - 2025 + 1 = \ln(1) = 0$$

This reflects 1 years of continuous reusability advancements.

Other indicators were estimated as follows:

Financial Investment:

$$f_2(2025) = \ln(8000) = 8.987$$

where $8 billion is the estimated annual cost (100 launches × $70M + operational costs).

Scientific Publications:

$$f_3(2025) = 2$$

— derived from relevant studies and databases (e.g., NASA ADS, Google Scholar).

Technical Upgrade Index:

$$f_4(2025) = 1 + 0.05\cdot(2025 - 2025) = 1$$

Expert Evaluations:

$$f_5(2025) = 7.5/10$$

based on online technical forums and performance metrics.[16].

These values were integrated into the composite development score using the following weighted model:

$$T(2025) = (0 \cdot 0.25) + (8.987 \cdot 0.15) + (2 \cdot 0.20) + (1 \cdot 0.20) + (7.5 \cdot 0.20) = 3.448.$$

All numerical data used in this article — including the projected financial investments, number of scientific publications, technological upgrade indices, reusability metrics, and expert evaluations for the Falcon launch vehicles from 2025 to 2030 — were derived from publicly available sources. These include official SpaceX data, academic databases such as Google Scholar, NASA ADS, arXiv, and analytical platforms like Reddit, SpaceflightNow, and Everyday Astronaut.[17],[18]. Some forecasted indicators were extrapolated and adjusted based on actual data to fit the modeling approach. For full transparency, all references and data sources are listed in the **"References"** section at the end of the article.

3. Results and discussion

In this study, a quantitative forecasting model was developed to assess the technological advancement of SpaceX's Falcon 9 and Falcon Heavy launch vehicles for the period of 2025 to 2030. The model incorporates five core factors—reusability technology, financial investment, scientific research output, technological upgrade index, and expert evaluations—each weighted according to their influence on technological progress. The table below summarizes the calculated technology development scores for each year, along with the annual growth rate:

Table 2

Forecasting results for falcon 9 (2025-2030)

Year	Falcon 9	Falcon 9 Growth (%)
2025	3.448	0%
2026	4.060	+17.75%
2027	4.599	+33.38%
2028	5.109	+48.17%
2029	5.603	+62.50%
2030	6.077	+76.25%

Table 3

Forecasting results for falcon heavy (2025-2030)

Year	Falcon heavy	Falcon heavy Growth (%)
2025	1.829	0%
2026	2.366	+29.36%
2027	2.617	+43.08%
2028	2.934	+60.42%
2029	3.020	+65.12%
2030	3.309	+80.92%

The results show a clear and steady upward trend in technological development for both Falcon 9 and Falcon Heavy over the forecast period. Falcon 9 is expected to reach a 76.25% increase in its technology development index by 2030 compared to the base year 2025. Similarly, Falcon Heavy shows even stronger relative growth, reaching approximately 80.92% by 2030, which can be attributed to gradual improvements in reusability, upgraded hardware components, and increasing research focus [19].

These values reflect the growing influence of consistent investment, iterative engineering improvements, and accumulated research and development activities. Notably, while Falcon 9 maintains a higher absolute score due to its maturity and higher flight frequency, Falcon Heavy exhibits faster growth because of its potential in heavy payload missions and strategic development efforts in the late 2030s.

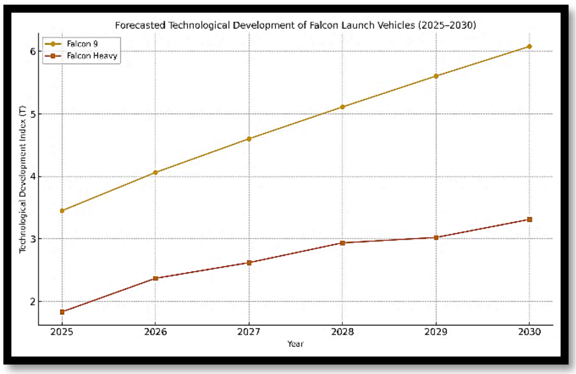

Fig. 1. Forecasted technological development of Falcon launch vehicles (2025 -2030)

From the data analysis, several conclusions can be drawn. Firstly, consistent technological advancement requires the integration of multiple interrelated factors: engineering innovation, budget allocation, academic contributions, and expert validation. Falcon 9's higher maturity level provides a strong foundation for stable incremental progress, while Falcon Heavy, though less utilized, benefits from intensified development efforts.

These trends indicate that future space technologies are likely to evolve not just through increased launches, but through synergistic improvements in design efficiency, resource optimization, and scientific collaboration.

From a practical perspective, such progress has wider implications. For countries like Uzbekistan, the increasing availability and affordability of launch services driven by reusable rockets could open new opportunities in Earth observation, agriculture monitoring, disaster management, and satellite communications. Establishing partnerships or knowledge transfer programs with companies like SpaceX could accelerate the development of domestic aerospace capabilities and support long-term national innovation strategies.[20].

In summary, the model not only projects optimistic growth in Falcon launch vehicle technologies but also highlights how such advancements can extend beyond their origin, offering broader economic and scientific benefits on a global scale.

4. Conclusion

This study focused on forecasting the technological development of Falcon 9 and Falcon Heavy launch vehicles for the period of 2025–2030 using a multi-factor mathematical modeling approach. The results demonstrated a steady and significant technological advancement trend for both rockets, particularly Falcon 9, which benefits from a higher flight frequency and more refined reuse technology.

The modeling incorporated five weighted factors: reuse technology maturity, financial investments, scientific publications, technical innovation index, and expert evaluations. The projected data revealed that Falcon 9's technological development is expected to grow by approximately **76.25%**, while Falcon Heavy is projected to

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grow by around **80.92%** by 2030, compared to their 2025 levels. This highlights the intensifying focus and investment in launch systems capable of supporting increasingly complex missions and commercial demand.

The study also confirms that multi-criteria modeling can effectively estimate future progress in aerospace technologies, especially when exact empirical data is limited. Such models can guide government bodies, private investors, and research institutions in their strategic planning and resource allocation.

Moreover, the findings underline potential opportunities for countries like Uzbekistan, where the growing commercialization of space and the availability of reusable launch vehicles may open doors to cost-effective satellite deployment, technological cooperation, and national aerospace program development.

Future research may enhance the model by integrating more dynamic variables, such as international policy shifts, unexpected technological disruptions, or new competitors in the launch industry.

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