Waleed Alhayaza
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Case study Tesla, Inc.

(Roadster, Model S, Model 3)

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Introduction & Background:

Tesla, Inc. is one of the most attractive brands in the Sustainable Energy industry. Since its founding in 2003, Tesla, Inc (formerly Tesla Motors, Inc) has dominated the electric vehicle (EV) and battery markets. The co-founders' vision was to develop electric vehicles that were not only cleaner, but better than internal combustion engine ICE. Tesla, Inc. mission is “to accelerate the world's transition to sustainable energy”, in which their scope expanded to include solar panels, Lithium-ion batteries, and solutions concerned with transportation and energy. This paper analyzes the global security environment, social and political security environment, and technology development environment for electric vehicles and mainly Tesla. Followed by assessment and analysis to identify key players, key assumptions, and key decisions that played a role in Tesla system development.

Environment for Electric Vehicles Industry:

In order to understand Tesla’s history and the development of its various models. It is important to look first at the history of the Electric vehicles and its industry as a whole. The first crude electric vehicle was developed in 1883 by Robert Anderson [1]. In fact the first concept and invention of an electric motor was discovered before the internal combustion engine in 1828, by Anyos Jedlik, a Hungarian engineer [2].

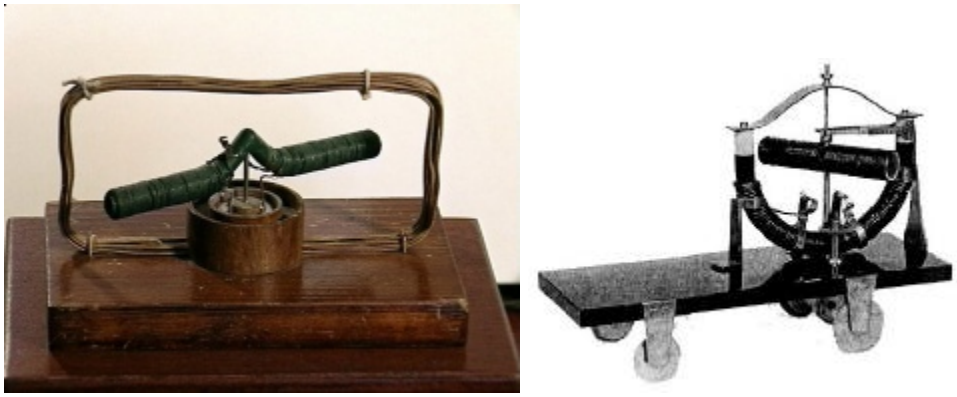

Figure 1: Jedlik’s electromotor. [2],[3]

However, historically several factors negatively affected the progress of electric cars. Mainly technology maturity, high costs, and the highly competitive market with internal combustion engines ICE.

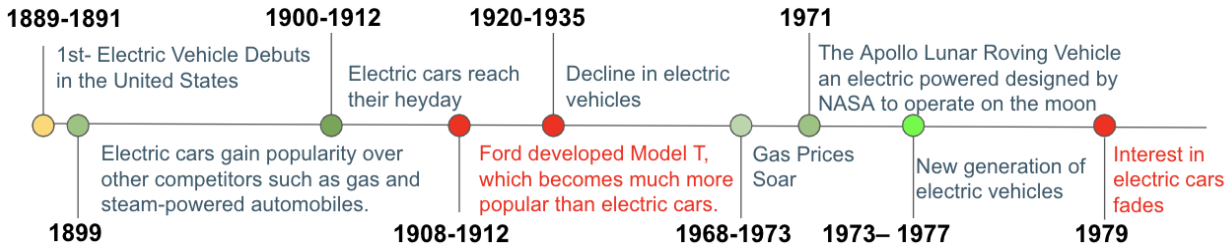

Figure 2:Electric Vehicles History.
Source: Department of Energy [1], **Waleed Alhayaza Summary**.

According to Battle's Laws as Heuristics "Don't look back. History never repeats itself", but as discussed by Gen. Pawlikowski history sometimes rhymes, in which it is to utilize the embedded wisdom instead of discarding it, and expand its value. Therefore in figure1, a summary of electric cars history in the United States before 1990 was developed for this case study, in which the "Green" color highlights the years where electric cars were popular or environmental conditions supported the growth of the EV industry. On the other hand, the "Red" color highlights challenges and low interest/demand for EVs.

Advantages such as low noise emissions, low carbon emissions, and the ease of use of electric cars in 1899 positioned them well in the market. Leading it to gain popularity over steam-powered and gas powered vehicles with urban residents, especially by women [1].

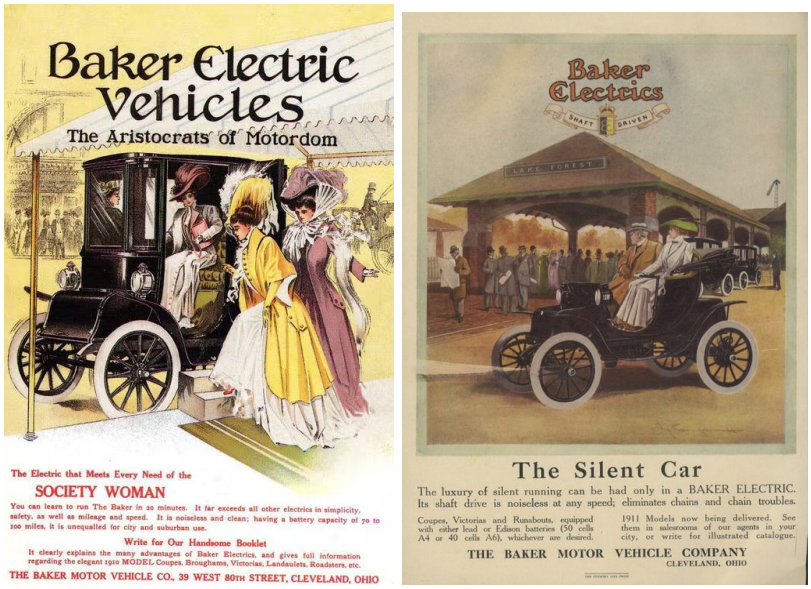

Figure 3: Electric vehicles Advertisement in 1899 & 1910. [1], [4].

However, the automobile industry was still in its early phases in the early 20th century and consumers had multiple options such as gasoline, steam, or electric cars. The electric

vehicles had several issues including limited range, speed, and high costs [5]. This led the majority of customers to buy gasoline cars. Mainly after the mass production of the Ford Model T, which was fairly available and affordable [5]. Model T was the first ICE vehicle to incorporate electric starter and electric light, leading it to take over the popularity of electric vehicles and increased the demand for ICE vehicles [10]. This raises the question of the advantages and incentives that supported the transition toward ICE vehicles. First, gas filling stations were well distributed around many locations, but charging stations were not available, especially in rural areas. Therefore, the range was a disadvantage due to technology maturity and a limited supporting system for charging stations. Furthermore, the high cost for electric vehicles was mainly due to high maintenance costs for its lead-acid batteries [5]. This led to a continued increase in the demand for ICE vehicles and a drop in demand for EVs.

The first oil crisis happened in 1973-1974, due to the oil embargo by the Arab members of OPEC against the United States in relation to Palestine-Israli conflict [6]. This crisis showed the importance of “Energy Independence " for the United States or to at least reducing its reliance on forigen oil. Furthermore, oil prices continuously increased after the embargo from $2.96 in 1970 to $12.52 in 1974 [7]. This was followed by the second oil crisis in 1979, which happened due to a drop in oil production in the wake of the Iranian Revolution. Hence, President Richard M. Nixon’s administration focused their efforts on taking new measures on energy conservation and development of domestic energy sources [6]. Followed by President Gerald R. Ford’s administration’s imposition of fuel economy standards [9]. This spurred investments in Electrical Vehicles including NASA’s Apollo Lunar, which runs on electricity to promote the profile of electric vehicles [1, 8]. However, in 1979 the interest in electric vehicles faded again due to drawbacks in performance and range [1]. Additionally the low prices of oil after the 1980s made it harder for electric vehicles to compete in the market.

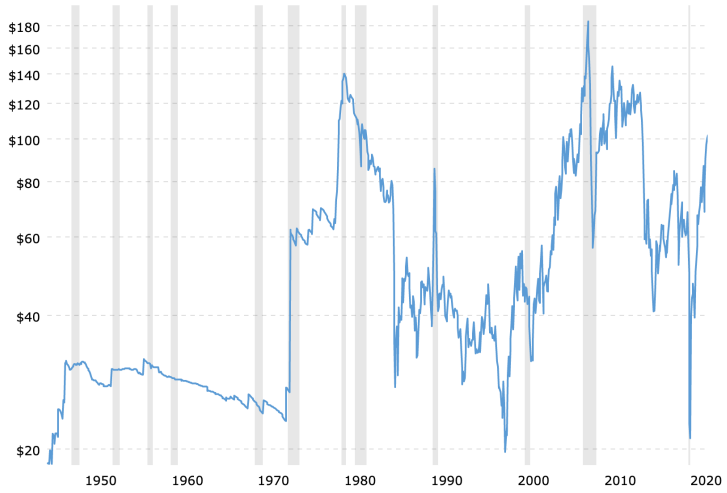

Figure 4: Crude oil prices 70 Year Historical Chart.

In order to address the 21 century energy challenges, which includes the increasing gasoline prices, rising worldwide demand for gasoline, and global warming. New federal state regulations renewed interest in electric vehicles [1].

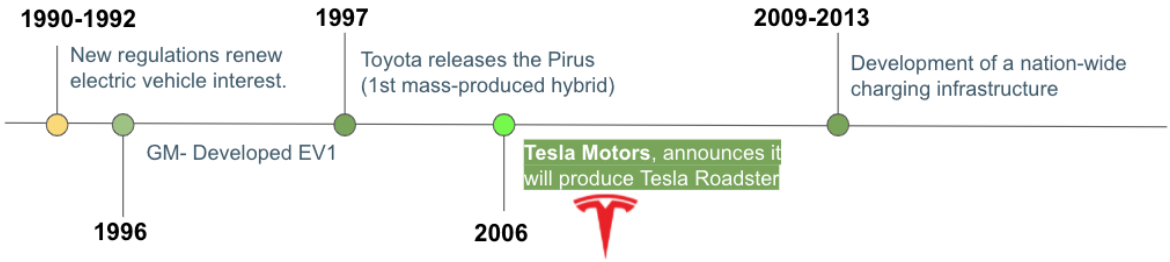

Figure 5:New generation of Electric Vehicles History.
Source: Department of Energy [1], **Waleed Alhayaza Summary**.

Regulations and incentives such as the 1990 Clean Air Act Amendment which focused on the major threats to the nations' environment laid the foundations for the development of the electric vehicles industry. General Motors developed EV1 from scratch to incorporate an advanced power control system with an exterior design that features lightweight materials and high performance aerodynamics [5]. Even though EV1 did not succeed to be commercially available. The project proved to be extremely successful from an engineering perspective. Later in 2003 inspired by the positive reaction to EV1 , engineers Martin Eberhard and Marc Tarpenning founded Tesla Motors [10]. Eberhard served as CEO and Tarpenning as CFO of the company.

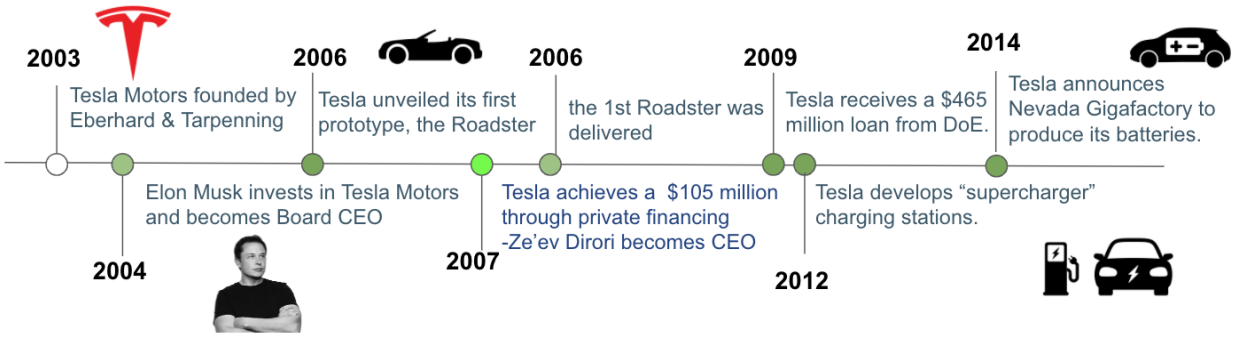

Figure 6:History the development of Tesla, and the whole energy system surrounding EVs.
Source: [10, 11], **Waleed Alhayaza Summary**.

When Tesla Motors was founded in 2003 the primary goal was to commercialize electric vehicles. The mission was to develop high performing, sustainable, and efficient electric cars that do not require the owners to compromise for driving electric vehicles. In doing so, Tesla Motors started working on Roadster, a premium electric sports car aimed at early adopters. The Roadster was meant to challenge the disadvantages that EVs had such as range and speed to achieve high

performance levels to compete in the market. After achieving this goal their vision was to expand to develop affordable mainstream vehicles. Eleon Musks explains in “The Secret Tesla Motors Master Plan” that Tesla’s goal is to build a luxury sports car. Then to utilize the profits to develop the technology to build affordable cars and zero emission electric power generation options [12].

Subrising to none, upon the release of Roadster in 2006 it became highly popular. The first electric car where the customers no longer need to compromise for performance for owning an electric car. Leading it to achieve multiple awards including the Time Magazine’s “Best Inventions 2006 - Transportation invention [14].

In 2007, Tesla collaborated with Daimler with the goal of accelerating the commercialization of electric drives globally [15]. In doing so, Tesla sells battery packs to Daimler and Toyota as they both have invested in Tesla and established a collaboration. Tesla developed the freestanding “supercharger” charging stations in California in 2012. It started with six stations, but plans to reach thousands worldwide [16]. Later in 2013, Musk revealed in TESLive that Tesla has three main goals: the introduction of an affordable electric car (Model S), development of additional Supercharger stations throughout the US, and the development of a sustainable energy system [17].

In fact by 2014, Tesla Motors announced the Nevada Gigafactory which officially opened in April 2022, the factory is essential to the development of Tesla’s sustainable energy system as it is meant to build the batteries that power Tesla’s devices. Therefore, the factory was essential to Tesla sustainability vision and to its entire business model [18].

However, Tesla faced multiple challenges such as high pressure in the schedule due to early exaggerated promises. And the development and testing of the new technologies including Tesla’s cutting edge Lithium battery technology and innovative electric powertrain. This has negatively impacted the first manufactured cars of Tesla’s different models including Roadster, Model S, and Model 3 as they proved to have several issues[19]. For example, Tesla recalled around 350 Roadsters due to a safety issue that could affect driver control over the vehicle. A second recall was made by Tesla in 2010 to fix the auxiliary cable in the Roadster for protection against potential fire hazard [23].

Tesla’s vision was to continuously develop and improve the car model and to achieve higher quality attributes in newer models. Furthermore, one of Tesla’s System of System innovations is that it regularly updates the software of its models using Tesla’s over the air software. This laid the foundations for Model S to receive multiple awards in different categories for its high performance, safety, and efficiency [21]. Tesla Model X is considered the safest, fastest, and most advanced sport car by the National Safety Administration ratings [22].

All in all, Tesla's vision is to deliver sustainable electric cars that have high performance, efficiency, and safety levels. Tesla have been achieving ratings in those quality attributes, but this was mainly due to the high supportability by Tesla's over the air software updates.

Key Players:

Throughout the development of Tesla and its various models different key players have been involved. Martin Eberhard Tesla Motors,Inc co-founder explained what triggered the idea of Tesla Motors, Inc. After the California Zero-Emission Vehicle (ZEV) Mandate, which required a continuous annual increase in the percentage of electric cars sold by companies [25]. Car dealers had an aggressive reaction against the mandate, in which they stopped developing EVs and filed a lawsuit in 2002 against the ZEV mandate [25,26]. This led Eberhard to invest in AC propulsion driven by his interest to work on the tzero model, which was an electric sports car. Early in 2004, Eleon Musk invested in the car model which became the Roadster later and Tesla Inc. was founded (formerly: Tesla Motors Inc.).

Government regulations and incentive programs laid the foundation for Tesla success. In fact, the 2020 Presidential election was an inflection point for Tesla Inc. This is mainly due to the green energy initiatives and efforts led by President Biden Administration. In doing so, President Bident, Department of Energy, Department of Transportation announced a $5 Billion investment for national charging stations. Additionally, President Biden explained that at least by 2030, %50 percent of the vehicles have to be either EV or hybrid [27]. Furthermore, Gov. Gavin Newsom signed an executive order to tackle the California state's transportation pollution, requiring all new passenger vehicles to be zero-emission by 2035. Therefore, in this case study several key players to Tesla's success are from the government due to their direct involvement to the EV industry.

Area of Improvement	Role	Organization	Individual names
Government laws, regulations, and incentives.	President of the United States of America	USA	Joe Biden
	California Governor	State of California	Gavin Newsom
Architect	Product Architect	Tesla, Inc.	Elon Musk
Acquirer	Vice President E-Drive and Future Mobility	Daimler AG	Prof. Herbert Kohler
System Engineering	Director of Powertrain systems architecture,	Tesla, Inc.	Drew Baglino

	modeling, and controls [24].		
Program management	Roadster program manager & CAD/PLM tech. manager	Tesla, Inc	Paul Lomangio
	Model S Program Director	Tesla, Inc.	Jerome Guillen
Technology development	Chief Technology Officer (CTO)	Tesla, Inc. & Prof. at Stanford University	Jeffery Brain “JB” Straubel
Oversight	Chief Designer	Tesla, Inc.	Franz von Holzhausen
Champion	Chief Executive Officer (CEO), Director, and product architect	Tesla, Inc.	Elon Musk

Table 1: Key Roles, Friedman framework

Key Assumptions:

Tesla’s cost estimation for the development cost of the Roadster was $25 millions. This was mainly because of underestimated assumptions for manufacturing costs.
Eberhard assumed that establishing an agreement with an established car manufacturing company (Lotus) would cut development costs.
Design Team Assumption: The Roadster’s targeted audience do not need any luxury interior nor advanced technology (screens, navigation).
Design Team Assumption: The Roadster design and manufacturing would be similar to hybrid vehicles. (Because they couldn’t compare it and benchmark it to any electric sport vehicle).
Tesla's ability to develop, build, and equip a new dedicated final assembly line at the Tesla Factory for high-volume Model 3 manufacturing while meeting the expected costs and schedule.
Tesla's ability to build and operate the Gigafactory in a timely manner in order to produce high volumes of high-quality lithium-ion cells.
Tesla's ability to integrate the lithium-ion cells into finished battery packs for the Model S and model 3 while maintaining target gross margins.

Tesla's ability to finish the Model 3 design and engineering plans on time, as well as provide final component designs to suppliers.
Tesla's capacity to attract, acquire, hire, and train qualified workforce, including employees on the production line, to operate the Tesla Factory and the Gigafactory.
Tesla’s mission is to accelerate the world’s transition to sustainable energy. Therefore, Tesla planned to manufacture Lithium-ion batteries as it is a major part of their business model.
Assumption of exponential growth in the demand for lithium-ion batteries to meet the market demand for EV industry and other applications that could use the batteries for their consumer electronics segment.
Elon Musk’s assumed that Tesla can operate fully online without any retail store.

Table 2: Key Assumptions [28] , [29]

Key Decisions & Outcome:

(Kindly note: the paragraphs are highlighted in colors to match the decisions with the key assumptions in table 2).

Tesla Roadster’s production started in 2008. Two years after the announcement of the first prototype in 2006. This was mainly due to manufacturing challenges, which led Eberhard to establish an agreement with Lotus to utilize their expertise in the automobile industry to cut development costs for the Roadsters which was assumed to be around $25 million. The cooperation with Lotus helped the Roadster to meet the required approvals by the Department of Transportation, National Highway Traffic Safety Administration, and Federal Motor Vehicle Safety Standards. However, it did not cut the development costs for the Roadster as there were many other factors involved. In fact, the Roadster development cost was around 140 million[31].

Chief design Holzhausen explained that Tesla models and EVs in general needed a new innovative design that is built from scratch to optimize the battery range and to reflect the beauty of electric vehicles. Unlike ICE or hybrid vehicles, spaces used for the fuel tank, transmission, and drive shaft are considered opportunity spaces to improve the utilization of the design. Furthermore, he explained that the early assumption regarding the Roadster’s interior and the technology incorporated in it was very basic. He explained that the Roadster limited technology was due to wrong assumptions about the customers' needs in electric sports cars. Unfourountly, this limited the features in earlier Tesla models such as screens, navigation,and other essential components that other competitors afford. However, he highlighted that the recent Tesla models incorporated advanced technologies far better than any other competitors.

In 2018, Tesla faced one of their biggest challenges in which they assumed their ability to manufacture 5000 (Model 3) vehicles per week. Therefore, based on that assumption Model 3 had a base price of $35,000. However, they were only able to manufacture 9,800 in their first

three months. After that the U.S Securities and Exchange Commission filed a fraud charge against Musk's misleading announcement [32]. This led Tesla to lose $1Billion in the 1st half of 2018.

Two of the major risks incorporated in Tesla's risk assessment were the willingness of the consumers to adapt with the transition to electric cars and the cities' infrastructure transition towards sustainable energy to incorporate charging stations [33]. In 2013, Tesla built Superchargers throughout North America to enable EVs travel coast-to coast. Furthermore, government efforts including building infrastructure for charging stations, raising awareness, and providing tax credits supported the whole SoS.

Milestone/Event	Description of the state of the system	Key decision makers	Impact of key assumptions	Impact of key decision	Impact of environmental influence
System milestones					
Ex:		Elon Musk, Tesla CEO	Tesla shall fully design, engineer, and manufacture Model S and Model 3	Initial phase: huge pressure on Tesla and they didn't deliver the promised number of cars. Second phase Tesla has factories in the 3 continents, in which they develop their batteries, motors, and operating system.	Tesla stock was negatively impacted when they did not achieve the targeted production.
Significant event in the environment					
Ex:	Tesla just started delivering their first orders for the Roadster	The Department of Energy	Tesla's ability to develop all-electric plug-in vehicles and to develop a facility in	The DoE gave Tesla $465 millions loan in 2009, which Tesla paid in full in 2013	The raising concerns against global warming and climate change.

			Fremont, CA.		

Table 3: Linking what happened to key decisions and decision makers

What if Different Decisions were made:

- What if the performance requirements for the 1st model developed by Tesla were less complex.
  - Tesla started first with development of the Roadster, a luxury electric sports car. Then Tesla announced its plan to utilize the profits to develop affordable electric vehicles. Did Tesla follow the right approach? What if Tesla started with the development of model S and model 3. Technology maturity was a challenge either way. The Roadster had to compete with high performance sports cars, but Model S and Model 3 would've required less speed.
- What if better integration of technology maturity assessment, manufacturing capabilities, and cost estimates and assumptions were incorporated in Tesla's architecture.
  - Model 3 had a base price of $35,000 when it was released, which led to an overwhelming demand that negatively impacted Tesla's brand name and led to huge financial losses.

Lessons Learned Description:

- Technology maturity and large scale manufacturing will challenge and derail almost any project plans or assessments.
  - Example: Musk's exuarated promise of Tesla's capability to manufacture 5000 cars a week.
- Technology realism and cost realism are essential factors to be considered in the architecture.
  - Example: The Roadster development cost was $140 million, which was five times the initial estimation ($ 25 million).
- Enterprise Architecture requires an interdisciplinary approach.
  - Requires understanding of budgeting, risk management, and technology development. Therefore, it requires building the right team.

- Major transformations such as the development of sustainable energy technologies require a serious interest and collaboration between the government and the private sector.
  - Tesla was able to achieve huge milestones that it could have not achieved without the support from the environment. This includes government incentives and regulations. Still this transformation needed the support of a champion (Elon Musk), which helped Tesla to survive the hard days.

- Systems should be built to be resilient, and adaptable. System architects need to work on keeping their options open as late as possible.
  - Earlier Tesla vehicles had very basic technologies, in which it didn't include common features such as navigation. However, Tesla developed the state of the art operating system that integrates automotive expertise with high quality software to boost the user experience. The system enables online installations for updates and it analyzes usage data to provide recommendations such as routing. This enables Tesla to continuously improve its models through online software updates.

- If an evolutionary approach was followed. Then there has to be an intermediate milestones to facilitate measuring progress.

Characteristic	
Ill-defined purpose with poor resource allocation	Tesla had well defined objectives, which was built upon and expanded. They received robust funding and had a very unique technology.
Inherently conflicting, but unresolved priorities	Elon Musk CEO of Tesla sets the priorities
Designed for a nonexistent market	Global warming concerns, pollution, and energy security (increase in gas prices) created a very strong market internationally.
Incomplete consideration of opponent's responses	Tesla assumed that the Saudi Public Investment funds would buy in. This led Tesla to offer exaggerated stock prices. However, the Saudi Public Investment fund ended up investing in Lucid motors, Inc.

Table 5: Tesla Scorecard based on Rechtin's Painful system architecture flaws.

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Characteristic	
Proper Environment	Strong interest globally. In addition to strong support by the POTUS, congress, and state governments. Huge support by DoE ($465 M)
Good initial choice	Initial choice focused on developing luxury electric sports cars (to justify high prices). Then to utilize profits to develop more affordable vehicles. However, technology and manufacturing limitations significantly increased the prices. They could have started with a luxury electric vehicle without targeting high speed performance. (Overly ambitious expectations at early phases).
Excellence of detailed design.	Recent models of Tesla proved to have an excellent design. However, early versions of model S and model 3 had many quality issues.
Thorough Development and Debugging	Tesla frequently debug and improve their models with online software updates.
Adaptiveness	With the peaks and valleys that almost every company goes through Tesla was able to adapt to challenges including during the pandemic. Mainly due to their advanced automated factories. Furthermore, the history of adapting to threats such as global warming and energy security.

Table 4: Tesla Scorecard based on Rechtin's Characteristics of well designed programs

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