**Proceedings of the ASME 2023**
**International Design Engineering Technical Conferences and**
**Computers and Information in Engineering Conference**
**IDETC/CIE2023**
**August 20-23, 2023, Boston, Massachusetts**

**DETC2023-116706**

# THE POTENTIAL FOR INCENTIVE STRUCTURES TO PREVENT SIGNIFICANT ENGINEERING FAILURES

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## ABSTRACT

*All complex designs emerge as the result of the decisions made by the design engineers. It can be shown that the designs are best when the preferences guiding the engineering decisions align with the overall system or corporate preference. But we know that all people make decisions based on their own personal preferences, which are unlikely to align well with the corporate preference. This research addresses the question, what mechanisms can be used to better align engineers' decisions to the system or corporate preference, but particularly such that major catastrophes might be prevented? Inspiration for this work comes from a number of very substantial losses that likely would have been prevented by the systems engineers had they the incentive to come forth with knowledge they certainly had. Examples include Boeing's experience with the 737MAX, which appears to be costing Boeing more than $100 billion, and Volkswagen's experience with the falsified emission testing of their diesel-engine vehicles, which resulted in over 31 billion euros in fines, penalties and other direct costs. We believe that incentive mechanisms could have been in place that would have prevented these very significant losses. Thus, we believe that there exist potential mechanisms that would benefit both the corporation and the engineers. We further believe that these mechanisms would not only improve corporate profitability but they have the potential to save many lives as well.*

**Keywords: Incentives, systems engineering, corporate profitability, system safety**

## 1. INTRODUCTION

Consistent with widely-accepted decision theory, all individuals make choices and decisions based on their personal preferences rather than the preferences of their employer. Personal preferences are shaped by various factors such as culture, education, experience, and emotions, and they determine how individuals evaluate and make decisions among different alternatives. Thus, engineering designs are the result of a composite mix of the preferences of the design engineers who work on the project. When the preferences of engineers are in agreement with the preferences of the company or the specific project, we can expect that the design produced will be better (that is, it will have a greater performance as measured by an overall system objective or preference) than a design that is the result of decisions made under a mixture of individual preferences. On the one hand, personal preferences are not easily amenable to change but, on the other hand, a person's choices depend on perceived outcomes such that incentives, which present alternative outcomes for design choices, hold the power to align decisions more closely to a corporate or project preference. Hazelrigg and Saari [1] show that alignment of preferences is a necessary condition for optimality in system design decision making, inferring that the use of incentives, while not changing the individual preferences of the engineers, may nonetheless better align their decisions with the overall system preference. This paper explores incentive structures that hold potential to align engineers' decisions more closely with decisions that would be made if all system design decisions were based on the corporate or system preference. This work is inspired by a number of major tragedies that likely could have been prevented if knowledgeable engineers had the incentive to speak out. Thus, we propose the following research questions:

(1) What mechanisms can be used to better align engineers' decisions to a system or corporate preference?

(2) What are the connections between each incentive structure and the behavior of the engineers?

(3) Which industries might benefit most by employing such incentive structures?

(4) Could disasters that have happened been prevented by properly incentivizing the engineers?

The ultimate goal of this study is to propose and evaluate incentive mechanisms and structures that might encourage engineers to act so as to prevent future, significant engineering failures. The rest of the paper is organized as follows. Section 1.1 describes our motivation from some historical systems engineering failures; Section 2 discusses the commonly used incentive mechanisms and structures; Section 3 presents the methods that are needed for incentive studies for the prevention of systems engineering failures; Section 4 discusses the data collection challenges; Section 5 provides an analysis of the incentives designed to reduce catastrophic events; Section 6 concludes the paper and provide thoughts about future incentive research.

### 1.1 Motivation

This study is motivated by several very substantial losses that likely could have been prevented by the systems engineers or whistleblowing actions [2] had it been clearly to their benefit to do so. One example concerns the two fatal crashes of the Boeing 737MAX aircraft, which occurred in October 2018 (Lion Air Flight 610) and March 2019 (Ethiopian Airlines Flight 302), and that cost 346 human lives and estimates of more than $100 billion in losses to Boeing [3]. The investigation into both accidents found that a malfunction in the aircraft's Maneuvering Characteristics Augmentation System (MCAS) caused the plane to dive repeatedly, leading to both accidents. The MCAS was designed to automatically adjust the plane's pitch attitude downward in the event of an impending stall. But in the accident cases, it activated due to a faulty angle-of-attack sensor, and the crew was unable to regain control of the aircraft [4]. The accidents led to widespread concerns about the safety of the 737 MAX and the MCAS system and eventually contributed to the global grounding of the 737 MAX fleet [5]. In November 2020, after 22 months of review by the FAA, the 737MAX was cleared to return to commercial service [6].

Another example is Volkswagen's emissions scandal, which came to light in 2015 [7]. It was discovered that the company had installed illegal software in its diesel-engine vehicles that cheated emissions tests. The software, known as a "defeat device", would detect when the car was undergoing emissions testing and alter the engine's performance to lower emissions levels and make it appear that the car was emitting fewer pollutants than it actually was. When the car was driven under normal conditions, emissions levels were much higher than what was reported during the tests. The scandal resulted in a loss of 31.3 billion euros, including compensation to affected consumers and damage to Volkswagen's reputation [8].

The explosion of the Space Shuttle Challenger is another example of a significant but preventable engineering failure. On January 28, 1986, the Space Shuttle Challenger broke apart and exploded shortly after liftoff, resulting in the loss of all seven crew members aboard. This was a significant event in the history of space exploration and engineering, as it was the first time a crew had been lost in-flight in the United States' space program. The disaster had far-reaching consequences, leading to a suspension of space shuttle flights for over two years and a renewed emphasis on safety and risk management in the space program. Overall, the explosion of the Space Shuttle Challenger serves as a reminder of the risks and challenges inherent in space exploration and the ongoing need for continuous improvement in engineering and safety practices.

All these accidents highlighted the need for proper testing and quality assurance in the design and manufacture of complex systems, and even more so the willingness of engineers to be honest and forthcoming with their opinions regarding the ultimate consequences of their decisions. We failed to find extant literature regarding the extent to which incentivizing engineers has contributed to disaster prevention (research question 4), leaving this as an open question. However, there is reason to believe that some individuals were aware of the risks and allowed them to occur. Given the huge losses associated with these events, we believe that it is possible to design incentive mechanisms that would prevent events of such consequence and that would simultaneously benefit both the organization and the engineers.

## 2. COMMONLY USED INCENTIVE MECHANISMS AND STRUCTURES

Incentive structures can be generally classified into behavior-based incentives and performance-based incentives [9]. Behavior-based incentives are rewards that are tied to specific behaviors or actions, rather than outcomes [10]. For example, a company might offer an employee a bonus for completing a project on time, even if the project is not ultimately successful. This incentive structure is designed to motivate employees to engage in specific behaviors that are considered important or desirable by the company. The idea is to reward employees for exhibiting behaviors that align with the company's values and goals, and to create a culture of accountability and high performance. Examples of behaviors that may be encouraged through behavior-based incentives include working hard, being punctual, following safe practices and procedures in the workplace, or adhering to company policies and procedures. For instance, an organization may offer a bonus to employees who meet certain productivity targets, or who consistently follow safety protocols. In addition to a bonus, incentive mechanisms could take other forms, such as promotions, public recognition, or disciplinary actions, and are typically tied to specific metrics or performance indicators. By linking rewards to specific behaviors, behavior-based incentives help to motivate employees to focus on the things that matter most to the organization and to make meaningful contributions to its success.

Performance-based incentives are rewards that are tied to specific outcomes or results. To be specific, a company might offer an employee a bonus based on the company's overall financial performance or based on the employee's individual sales or productivity. This type of incentive is intended to encourage employees to work harder and achieve better results, as they know that their efforts will be rewarded. For example, suppose a company wants to implement a performance-based incentive program that focuses on improving the quality of their engineers' work. A possible incentive mechanism could be providing training opportunities for engineers to improve their skills and knowledge. The incentive program could be designed systematically for recognizing and rewarding engineers who consistently produce high-quality work. Much of the incentive literature focuses on the study of performance-based incentives [11]. Dating back to 1990, Banker et al. [12] launched a field experiment that analyzed the impact of a performance-based compensation plan on the sales of a retail establishment over multiple time periods. The researchers used panel data from 15 retail outlets over a period of 66 months to observe the effects of the plan. The study found that there was an increase in sales after the implementation of the plan, and this effect continued to grow over time. In 2007, Lavy [13] discussed the potential benefits and challenges of implementing a performance-based pay system for teachers. While tying pay to performance could improve the education system by attracting and retaining the most productive teachers and clarifying teaching goals, measuring individual teacher performance can be difficult. The author concludes that despite the practical challenges, carefully designed performance-based pay systems can motivate teachers to improve their performance and benefit students. Some incentive studies have researched the impact of performance-based incentives on requirements-based engineering design. Vermillion et al. conducted studies [10, 14] to assess the effort level of design teams with fixed and linear performance-based incentive mechanisms. They utilized a game theoretic principal-agent framework to create a conceptual model for design processes based on both requirement-based and value-driven design.

Companies can employ incentives individually or in combination to motivate and reward employees. For example, employees might be offered a performance-based bonus based on the company's financial performance. For those who consistently arrive to work on time, or who meet certain safety standards, a behavior-based bonus might be offered. Additionally, the selected incentive structures depend on the type of work and the level of the employees. In sales teams, performance-based incentives may be more common, while in the production teams, behavior-based incentives such as safety or quality awards, may be more prevalent.

The relationship between incentive structures and the behavior of engineers can be either positive or negative (research question 2). On the positive side, each incentive structure can motivate specific behaviors of the engineers to achieve better overall performance of the company, which is beneficial for the engineering industry. However, a key factor in the design of an incentive program is that the program should promote the desired behavior while not creating undesired side effects. For example, overemphasis on profit could lead to short-term decisions to cut corners, resulting in lowered quality that eventually impacts the salability of a product. Incentives that encourage corporate loyalty could result in decisions to cover up inappropriate behavior or to fail to bring to light design faults that could lead to future liability issues [15, 16].

In order to get engineers to be forthright and honest, we believe that they need to have something at stake. It would appear that this may not have been the case in the examples noted above. Something at stake could be partial ownership in a product or system so that, even if an engineer leaves the company, he or she still gets rewards for the work performed. For example, ownership could mean a share of profits generated by a product or system over its lifetime or less direct, stock in the company itself. Consider a case where a catastrophic accident had a cost of $10 billion. If 1,000 engineers were involved in the design of the product or system, and if they prevented a loss of this magnitude from occurring, a lifetime bonus of $1 million to each engineer would have resulted in a $9 billion gain to the company. Of course, the likelihood of such an event must be figured into the computation, but the numbers are enticing nonetheless, and the ownership benefit to the engineers could be viewed as insurance against the incurrence of preventable accidents.

Incentive studies for employees are vital to help to align employee goals with the overall goals of the organization, especially in complex systems [17]. Previous studies have explored incentives for employees in technology firms [18], optimal incentive for teams [19–21], and optimal contracts for workers [22–24]. However, in systems engineering, there is a scarcity of incentive research for engineers. As a result, there may be limited understanding of what works best in terms of encouraging and recognizing the contributions of an engineering workforce. The design of effective incentive mechanisms has been a challenging task. It requires a deep understanding of an engineer's performance and the organizations's objectives to develop an appropriate incentive system that encourages desirable behaviors and avoid possible side effects. Fortunately, the recent development of appropriate mathematics, including game theory and artificial intelligence, offers opportunities for expanding incentive studies.

## 3. INCENTIVE EVALUATION METHODS

The methodologies including game theory, mechanism design, utility theory and optimization, and machine learning have been employed to study the incentives for employees.

### 3.1 Game Theory

Game theory is a branch of mathematics that studies decision-making in strategic situations where the outcome of an individual's decision depends on the decisions of others [25]. The earliest work in game theory can be traced back to the 18th century, with the development of the concept of the "minimax" strategy in the game of chess [26]. In this strategy, a player seeks to minimize their maximum possible loss, by considering all possible moves and their opponent's possible responses. However, it was not until the mid-20th century that game theory began to emerge as a formal discipline of mathematics. The development of game theory as a field is often attributed to the work of John von Neumann and Oskar Morgenstern [27], who introduced many of the fundamental concepts and mathematical tools of game theory in the 1940s. Their theory provided a framework for analyzing strategic interactions among individuals or organizations with conflicting interests, and formalized the concept of a "game" as a set of players, strategies, and payoffs. The current theory includes several key concepts, such as dominant strategies and the minimax theorem that are central to the current theory. Another major contributor to the development of game theory was John Nash, who introduced the concept of a Nash equilibrium in 1950 [28]. Nash's work showed that, in many games, there exists a stable equilibrium where no player has an incentive to deviate from their chosen strategy, given the strategies chosen by the other players. This concept has been widely applied in economics, political science, and other fields to analyze strategic behavior in real-world situations [29]. Other notable contributors to the development of game theory include Lloyd Shapley, who made significant contributions to the study of cooperative games and introduced the concept of the Shapley value [30]; Thomas

Schelling, who used game theory to study bargaining and conflict resolution [31]; and Robert Axelrod, who applied game theory to the study of cooperation and evolution [32].

In the field of systems engineering, game theory can be used to analyze the strategic behavior of engineers given design incentives that align their interests with the company's objectives, particularly in situations where the behavior of one engineer can affect the behavior of others. One approach to using game theory to study incentive mechanisms for engineers is to model the interactions between engineers as a game, where each engineer's actions affect the outcomes for themselves and others [26]. In this game, the engineers are the players, and their actions are their strategies. The rewards or incentives for each engineer depend on both their own actions and the actions of other engineers. For example, consider a situation where engineers are working on a project that requires coordination between different teams. Each engineer has a choice between working on their own tasks, or helping other engineers with their tasks. If all engineers choose to work on their own tasks, the project may be completed, but there may be delays or quality issues due to a lack of coordination. If all engineers choose to help others, the project may be completed more efficiently and with higher quality, but each engineer may not get as much individual credit or recognition. This situation can be modeled in game theory as a coordination game. The engineers are the players, and their actions are to work on their own tasks or to help others. The rewards for each player depend on the choices of other players as represented by a payoff matrix such as that in Table 1.

**TABLE 1: A PAYOFF MATRIX**

| | Work independently | Help others |
|---|---|---|
| Work independently | 5,5 | 1,3 |
| Help others | 3,1 | 2,2 |

In this payoff matrix, the numbers represent the rewards for each player based on their choices. For example, if both players choose to work on their own tasks, they both receive a reward of 5. If one player chooses to work on her own tasks and the other chooses to help, the first player receives a reward of 1 and the second player receives a reward of 3.

This game-theoretic model can be used to analyze the incentives for each player to choose a particular strategy. For example, if the engineers are risk-averse and prefer to avoid low-payoff outcomes, they may both choose to work on their own tasks, even though this may not be the most efficient outcome overall. If the engineers are more risk-tolerant and willing to take a chance on a higher-payoff outcome, they may both choose to help others, resulting in a more efficient outcome for the project as a whole. By using game theory to model the interactions between engineers, we can analyze the incentives and outcomes of different incentive mechanisms. For example, we could experiment with different reward structures, such as giving bonuses for successful completion of the project, or giving recognition to individual engineers for their contributions to the project. We could also experiment with different communication strategies, such as providing more frequent updates on the progress of the project or encouraging more open communication between teams.

### 3.2 Mechanism Design

Whereas game theory deals with interactions between two or more decision-making entities, mechanism design deals with the theory of designing the game. The concept of mechanism design was first introduced by Nobel laureate economist Leonid Hurwicz in 1960 [33]. Hurwicz sought to develop a framework for analyzing how information asymmetry affects market outcomes and how to design mechanisms that could achieve efficient outcomes even in the presence of such asymmetry. Since then, the field of mechanism design has continued to grow and expand, with numerous economists making valuable contributions to the development of mathematical tools and techniques for the design and analysis of complex mechanisms [34–36].

A well-known mechanism design was applied in auctions, and further in resource allocation. In the early 1960s, Vickrey [37] developed the second-price auction, which results in the highest bidder winning an auction but paying only the second-highest bid as the price. In this mechanism, currently in use by eBay, bidders are incentivized to bid their true valuations for the item being auctioned, since bidding higher than their true valuation risks winning the bid, but at a price higher than the value they place on the object, and bidding low risks failing to win the bid at a price that is lower than they were willing to pay. This mechanism has become a commonly used mechanism for selling goods and services, since it ensures that the item is allocated to the bidder with the highest valuation while minimizing the overall cost paid by the winner. Later, Myerson expanded Vickrey's work by designing mechanisms for efficient allocation of resources with private information [34]. His auction requires sealed bids, and the winner pays the true value of the item, which is the second-highest bid submitted by another participant. Myerson's contributions have had a significant impact on mechanism design and led to the development of many new mechanisms used today.

In systems engineering, mechanism design can be used to incentivize engineers to make decisions that result in a desirable outcome for the system as a whole. The use of game theory and Nash equilibrium can be useful in designing these incentive mechanisms by modeling the behavior of the engineers and identifying strategies that promote desirable outcomes. For example, suppose a company wants to incentivize engineers to prioritize safety in their designs to prevent engineering failures. The company designs an incentive mechanism that offers a bonus to engineers who identify and mitigate safety risks in their designs. The bonus amount is proportional to the importance of the safety risk identified and mitigated. In this mechanism, a Nash equilibrium would occur if each engineer identifies and mitigates safety risks in their designs to the best of their abilities, given the incentive provided by the bonus. Each engineer is incentivized to identify and mitigate safety risks that are likely to result in the highest bonus payout, while also ensuring that the safety of the design is not compromised. If an engineer fails to identify and mitigate safety risks, they risk missing out on the bonus payout, which would negatively impact their payoff. Thus, in this Nash equilibrium, each engineer is incentivized to prioritize safety in their designs, resulting in a lower risk of engineering failures. Additionally, the principal-agent framework has been used to design incentives in which the company (the principal) offers incentives to the engineer (the agent) to achieve a desired outcome, such as a successful product launch or a decrease in engineering failures [38]. To design an optimal incentive mechanism, the principal needs to take into account the agent's incentives and the agent's private information, which can affect the agent's behavior. For example, if the agent knows more about the likelihood of an engineering failure than the principal, the agent may have an incentive to hide this information to avoid being blamed for the failure. To overcome this problem, the incentive mechanism can be designed to provide the agent with incentives to reveal their private information truthfully.

### 3.3 Utility Theory and Optimization

Utility theory is a mathematical framework that is used to model decision-making under uncertainty. It provides a way to measure the subjective, risk-adjusted value or "utility" that an individual assigns to different outcomes, and uses these utilities to recommend decisions in situations where the outcomes are uncertain. Utility is an axiomatically correct measure of value under uncertainty such that expected utility is a valid, deterministic ordinal measure that rank-orders outcomes of alternatives for a given decision. That is, it is a mathematically valid objective function. Optimization, on the other hand, is a mathematical technique that is used to find the best solution to a problem given certain constraints. In this mathematical context, and to be precise, decisions are made only by individuals. Groups do not make decisions. Rather, groups have emergent behaviors that are the result of decisions made by individuals in the group *and* the rules by which the members of the group interact. Thus, utility theory and optimization apply to the decisions of individuals in a group, but game theory is the mathematic that describes the behavior of the group.

In 1738, Daniel Bernoulli [39] responding to what is now known as the St. Peterburg paradox posed by Nicolaus Bernoulli in 1713, proposed the concept of expected utility, which was later shown by von Neumann and Morgenstern to be, under a compelling set of axioms, the only valid measure of risk-adjusted value under uncertainty. The work of von Neumann and Morgenstern has led to the study of strategic decision-making in economics [27]. Hurwicz pioneered the field of mechanism design, which uses optimization techniques to design incentive-compatible mechanisms that align the interests of agents with those of a principal [33]. His work laid the foundation for much of the modern research on incentive structures in economics. Tirole [40] has made many contributions to the study of incentives, including his work on mechanism design and contract theory, which uses optimization techniques to design contracts that incentivize agents to take actions that benefit the principal.

Utility theory can be used to model an engineer's preferences by assigning a utility function that represents the engineer's preference for different outcomes. For example, an engineer may have a higher utility for a higher salary, but also value job security, work-life balance, and opportunities for career advancement. By eliciting the engineer's preferences through surveys or interviews, a utility function can be constructed that captures these preferences. Once the utility function is defined, optimization techniques can be used to maximize the engineer's expected utility subject to the risk of engineering failures.

The principal-agent framework belongs to mechanism design and has been used to design incentives in which the company (the principal) offers incentives to the engineer (the agent) to achieve a desired outcome, such as a successful product launch or a decrease in engineering failures [38]. To design an optimal incentive mechanism, the principal needs to take into account the agent's incentives and the agent's private information, which can affect the agent's behavior. For example, if the agent knows more about the likelihood of an engineering failure than the principal, the agent may have an incentive to hide this information to avoid being blamed for the failure. To overcome this problem, the incentive mechanism can be designed to provide the agent with incentives to reveal their private information truthfully.

Other optimization techniques can also be used for optimal incentive design, such as linear programming, dynamic programming and game theory. The general idea is to design a mechanism that maximizes the engineer's expected utility while minimizing the risk of engineering failures Together, utility theory and optimization provide powerful tools for understanding decision-making and designing effective incentive structures that encourage engineers to work toward outcomes that are beneficial to the organization while accounting for the possibility of engineering failures.

### 3.4 Machine Learning

Machine learning is a sub-field of artificial intelligence that focuses on the development of algorithms that allow computer systems to learn from data and make predictions. The concept of machine learning was first introduced by Arthur Samuel in 1959 [41], who defined it as the ability of a machine to learn without being explicitly programmed. The development of neural networks and deep learning in the 1980s and 1990s further advanced the field of machine learning [42, 43]. In recent years, the availability of large datasets and powerful computing resources has led to significant progress in machine learning, particularly in the areas of computer vision, natural language processing, and reinforcement learning.

Although machine learning has been widely used in various fields, such as natural language processing, computer vision, and recommendation systems, its application to incentive mechanism design for employees is still limited. One possible explanation could be the difficulty in gathering relevant data. Most studies have employed machine learning techniques to learn the parameters of optimization models, such as linear programming and integer programming, which are subsequently used to optimize reward allocation [21]. These models aim to maximize the profit of the company while maintaining the motivation of employees. However, the traditional optimization models usually assume that employees have perfect information, which is not always the case in reality. Therefore, the incorporation of machine learning into incentive mechanism design for employees has great potential in improving the accuracy of the optimization models and addressing the information asymmetry challenge.

To prevent engineering failures, incentive mechanisms can be designed to encourage engineers to be more forthright regarding design problems of which they are aware. By bringing design deficiencies to light, the likelihood that they are addressed would be significantly increased. But such incentives would likely work best in an organization whose culture does not punish employees for pointing out problems, and the reward for coming forward with such problems would likely need to endure for the lifetime of the product or system. Incentives could be given to engineers who provide high-quality data and perform regular maintenance checks. For instance, a company may offer bonuses or promotions to engineers who contribute to a predictive maintenance program and keep machines in good condition. One approach, predictive maintenance, has been used to prevent equipment failures and improve safety [44]. It is a machine learning-based approach that predicts when a machine is likely to fail, allowing maintenance to be scheduled before the failure occurs. This approach has been used in various industries, including manufacturing, energy, and transportation, and has great potential on the application of incentive mechanism design for the engineers.

## 4. DATA COLLECTION CHALLENGES

Incentive studies for engineers are crucial in determining the optimal amount of rewards to be provided to them for achieving their goals. There are many ways to collect the data. One possible data collection way is to design and distribute surveys to the engineers in a corporation to gather information about the factors that affect their decisions and preferences. Surveys can help to collect data on the types of incentives they find motivating and can provide insights into the factors that motivate them to achieve their targets. Surveys can be distributed to managers to collect various aspects of engineers' performance and effort level. However, collecting reliable data for these studies can be challenging due to several factors.

One of the main challenges is the subjective judgments involved in evaluating an engineer's performance. Evaluating an engineer's performance involves considering various factors such as productivity, quality, and creativity. However, personal opinions or preferences can influence the evaluation process, leading to inconsistencies in the incentive calculation. For instance, some managers may evaluate an engineer's performance based on their personal preferences, rather than objective measures such as productivity or quality. This can result in unfair incentives that do not accurately reflect the engineer's performance.

Data on an engineer's performance can also be complicated and require sophisticated analysis to derive meaningful insights. An engineer's performance may depend on various factors such as their experience, training, and the complexity of the task. Collecting data on all these factors can be challenging, and it may be difficult to extract meaningful insights from the data collected.

Another challenge in collecting data for incentive studies is ethical concerns such as privacy issues or discrimination concerns. Companies must ensure that the data collection process is ethical and that the engineer's privacy is respected. Data collection methods should be designed in such a way that they do not violate the engineer's privacy or discriminate against them based on their gender, race, or other characteristics.

To address the challenges of collecting reliable data for incentive studies, companies can design particular mechanisms that are embedded into the data collection process. A possible mechanism could be requiring at least three supervisors or managers to evaluate the performance of each engineer. The final performance level could be the average of the total evaluation scores. Another possible mechanism is to incorporate peer evaluation into the performance assessment process. In this method, the individual evaluations of employees are compared with the overall results. If an employee's evaluation appears to be biased or unreasonable, it can be discarded from the final assessment. This helps to ensure that evaluations are fair and accurate, as employees are less likely to provide biased or dishonest assessments if they know that their evaluations will be compared to those of their peers. These mechanisms can motivate engineering managers to provide more objective and honest responses, thereby minimizing the impact of subjective judgments on the data collected.

Furthermore, companies must ensure that the data collection process is ethical and respects the engineer's privacy. This can be achieved by using secure data collection methods that protect the engineer's personal information and prevent any discrimination or bias in the data collected. In addition, companies can provide clear guidelines to the evaluators to ensure that they follow a fair and objective evaluation process that takes into account only objective measures of performance. By implementing these measures, companies can collect reliable data that accurately reflects the engineer's performance and motivates them to achieve their goals.

## 5. INCENTIVES DESIGNED TO REDUCE CATASTROPHIC EVENTS

In our review of the literature, we have not found any studies that relate specifically to engineers and their ability to predict and prevent catastrophic events. We feel that with respect to the examples we provide above, the engineers were well aware of problems that results in catastrophic losses but chose not to speak out, likely because they felt it not in their best interest to do so. While whistleblowing may play a crutial role in preventing disasters as a last resort [45], this heroic action can also result in negative consequences for whistleblowers, including retaliation from their employers and difficulty finding future employment in the industry. Nonetheless, in the examples cited, it seems clear that the company would have benefited had they done so. For this reason we believe that, particularly for companies dealing in very high value products or systems, such as commercial aircraft, automotive product lines, nuclear power plants and such, the magnitude of the potential losses are such that these companies stand to gain significantly by providing a positive outcome for engineers who choose to speak up. As examples of such incentive structure, we suggest the variations of the following basic incentive strategies (research question 1).

### 5.1 Stock Ownership

In this incentive mechanism, engineers are provided with a stock bonus or stock options that would reward them for the success of their work on the product or systems. The stock ownership incentive could take several forms including gifting stocks to employees, opportunities to purchase stock at reduced prices, stock option plans, and creation of employee stock option plans (ESOP). The duration of the stock ownership can vary, but it is typically a long-term investment in the company. This incentive is generally provided to senior management and executives; however, it can also be offered to engineers as a reward for their performance. The amount of stock or stock options provided is usually determined based on the engineer's contribution to the company and their level of responsibility. Stock ownership can be a powerful incentive tool for engineers, as it fosters a sense of ownership and engagement in the company's success. By giving engineers a direct financial stake in the organization, they are more likely to be invested in its long-term growth and sustainability, whether or not the engineers benefit the company. On the other hand, this incentive strategy has a potential to attract and retain top talent in the engineering field. The prospect of earning a financial return on their investment can provide engineers with a sense of security and stability, which may help to improve retention rates within the organization.

Despite the advantages of providing stock options, this incentive strategy has a few potential side effects. The strategy of incentivizing engineers with stock ownership focuses on the profitability of the overall company but lacks specificity to the project for which the incentive is intended. The incentive is not tied to specific goals or objectives, which can lead to a lack of direction and focus among engineers. Moreover, stock options depend on stock price rather than product performance. This indicates that even if the company is not performing very well, the stock price can still increase due to external factors such as market conditions. As a result, employees may receive a reward despite the company's underperformance, which can lead to unfairness among employees and demotivation. Furthermore, stock options can remove the focus from the specific behavior desired and have side effects on the company's overall performance. For instance, stock options can incentivize employees to focus on short-term results rather than long-term growth, negatively impacting the company's sustainability and competitiveness.

### 5.2 Ownership of Product or System

Providing ownership of product or system could be a powerful strategy to motivate the engineers to achieve outstanding results. When engineers are given ownership of a product or system, they have a direct stake in its success, which can drive them to work harder and be more invested in its development and performance. The duration of this incentive strategy is dependent on the specific organization and project. Ownership can be granted for the product or system's entire life, limited to a specific timeframe, or until certain milestones are achieved. This incentive is usually reserved for senior engineers, project leads, or other key contributors but could be applied at all levels of the engineering workforce. The determination of ownership may be based on various factors, such as the level of contribution, the value of the product or system, or a combination of both. Game theory and mechanism design can be employed to develop this incentive by creating a fair allocation mechanism. A formal agreement or contract typically outlines the terms of ownership, such as the percentage owned and the associated rights and responsibilities. This incentive can lead to improved collaboration among team members by sharing insights, identifying potential problems, and developing more effective solutions. Moreover, the provision of ownership of a product or system to engineers can serve as a compelling incentive to attract highly skilled and proficient individuals to a company. Through the offer of a stake in the success of a project, engineers become more engaged and invested in the outcome of their work. Such ownership creates a sense of responsibility, accountability, and accomplishment that can motivate employees to deliver their best performance. This can result in higher quality work and more successful outcomes for the company, thus enhancing its overall reputation and competitiveness. Additionally, the ownership incentive can foster a strong sense of commitment and loyalty among employees towards the organization, thereby reducing the risk of high employee turnover and loss of valuable talent.

There are three noteworthy concerns to consider regarding this incentive strategy. Firstly, it requires a supportive company culture that prioritizes employee value. Companies with such values are more likely to recognize the benefits of providing product ownership to engineers. Secondly, there is a risk of creating an unequal distribution of rewards, which may lead to a decrease in motivation and satisfaction for non-owners. Lastly, there is the possibility of terminating engineers before the product is completed, which may occur when a company values short-term goals over long-term sustainability and employee loyalty.

### 5.3 Profit Sharing at Company Level

Profit sharing at the company level is considered a valuable incentive for engineers due to its potential to foster employee engagement and commitment. The duration of profit-sharing incentives for engineers varies based on company policies and agreement terms. Some companies offer annual profit-sharing, while others provide it on a project-by-project basis or for a set time. Eligibility criteria like performance metrics or length of service determine the employees who can receive profit-sharing. Typically, profit-sharing is based on the company's financial performance, with a portion of profits allocated to eligible employees using an optimizaiton model, a predetermined formula, or based on the level of contribution. A formal agreement or contract outlines the percentage of profits allocated, payout structure, and eligibility criteria to guarantee transparency and clarity. Through profit sharing, engineers are provided with a financial stake in the success of the organization, thereby increasing their investment in the company's outcomes. This can result in a stronger sense of collaboration and teamwork among engineers, in addition to enhancing their motivation to perform to the best of their abilities. Profit sharing can also encourage a culture of innovation and creativity, as engineers may be more inclined to take risks and explore novel ideas when they recognize that their contributions can directly impact the company's bottom line. Furthermore, engineers may feel more comfortable speaking up, when they have quality or safety concerns in their engineering products.

While providing profit sharing incentive can be a powerful tool to motivate current employees, it also raises important concerns. One such concern is that the rewards would only be provided to the current employees who are working on the project, and not to the previous employees who may have made significant contributions in the past. This can create feelings of inequity and demotivate current employees who feel undervalued. Additionally, there is the potential for the bonus system to be manipulated by management, which can lead to further demotivation and a lack of trust in the organization.

### 5.4 Direct Bonus

Direct bonuses are a common incentive offered to engineers and can vary in duration depending on the company and project. Typically, they are provided upon the completion of a project or the achievement of specific goals or milestones. This incentive may be offered to all engineers involved in the project or reserved for those who have made significant contributions. Determining the direct bonus may be based on factors such as project completion time, quality standards, safety metrics, or customer satisfaction. The bonus amount offered by a company may be determined by a predetermined formula that could be fixed or proportional to the level of contribution or performance. Terms and conditions, including eligibility criteria, payout structure, and the total amount allocated, are outlined in a formal agreement or contract to ensure transparency and equity. Direct bonuses can motivate engineers to prioritize quality and safety in their work, as it provides a financial incentive for them to perform at their best. Engineers may take extra care in their design and decision-making processes, as they know that their work will be evaluated and rewarded based on its overall effectiveness and success in preventing engineering failures. This can result in increased attention to detail, improved communication among team members, and a stronger culture of safety within the engineering organization. This strategy can also encourage engineers to take a proactive approach to identifying and addressing potential engineering failures before they occur. By conducting thorough risk assessments and implementing preventive measures, engineers may be more successful in avoiding failures altogether rather than reacting to problems after they arise. Ultimately, direct bonuses have the potential to foster a culture of excellence and safety in engineering organizations, as well as attract and retain top talent in the field.

One potential concern with this incentive strategy is that direct bonuses are often provided upon completion of the job, which may create apprehension among engineers about being laid off just before the project is finished in order for the company to avoid paying out bonuses. This concern may increase insecurity and decrease motivation among engineers. Furthermore, direct bonuses may not accurately measure the real performance of engineers in preventing disasters. This is because the success of catastrophic events prevention efforts may not be apparent until months, or even years after the project has been completed. Another drawback of this incentive strategy is that it is only apply to engineers who are employed by the organization. If engineers make a significant contribution to the project but leave the company in the future, they will not receive any further incentives for their excellent work. This lack of recognition and reward can lead to decreased morale and motivation among engineers, especially if they feel that their contributions are undervalued by the company.

## 6. CONCLUSION

In this paper, we have explored various incentive structures and strategies that can be employed to design effective incentives for engineers. The incentive structures can be broadly categorized into behavior-based and performance-based incentives. Our analysis has revealed that incentives can take different forms, such as stock ownership, ownership of product or system, profit sharing at company level, and direct bonuses. From our analysis, we suggest that the combined approach of providing ownership of a product or system and implementing profit sharing at the company level is a more effective incentive structure than others. We also suggest that industries with longer production runs, such as commercial aircraft, automotive product lines, and nuclear power plants, may benefit the most from such incentive structures (research question 3). This approach offers engineers a vested interest in the long-term success of a project, which can foster greater engagement, accountability, and willingness to voice concerns to prevent engineering failures.

Additionally, a combination of approaches including game theory, mechanism design, utility theory and optimization, and machine learning can be utilized to study the incentives for engineers. However, collecting reliable data for these studies can be a challenging task due to the involvement of subjective judgments, ethical concerns, and the complexity of the data involved. To overcome these challenges, we recommend designing appropriate data collection methods, such as surveys with appropriate mechanism design, to gather accurate and reliable data.

In many cases, incentive structures have been recognized for promoting and facilitating negative actions and attitudes. The engineers may engage in arguments regarding the significance of their decisions in the overall system, which can adversely affect collaboration and result in a decline in the overall system's performance. This is because people may be incentivized to focus on their own benefits, cut corners or ignore potential risks in order to achieve their personal goals. As a result, it is essential for companies to carefully design their incentive structures to ensure they motivate positive behavior, rather than encourage harmful practices.

In addition to the incentive plans, we suggest that large engineering organizations should have well-defined pathways for whistleblowers to report unethical behavior. These pathways should ensure that whistleblowers are protected from retaliation and that their concerns are addressed in a timely and effective manner. This practice could be considered a double safety measure for preventing disasters.

Further investigation could focus on developing and assessing the suggested incentive plan, which incorporates product ownership and profit sharing. Despite the advantages of incentives, the potential drawbacks of their implementation warrant further exploration. In general, as technology advances, it becomes feasible to explore these research avenues and design more efficient incentive strategies for engineers working in intricate systems, no matter for profit or non-profit organizations.

## ACKNOWLEDGMENTS

This work has been supported by the National Science Foundation under award CMMI-1923164.

 

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