A Virtue Ethics Analysis of the Programmers of the Patriot Missile System

STS Research Paper
Presented to the Faculty of the
School of Engineering and Applied Science
University of Virginia

By

Godwin Oluwafemi

April 12, 2024

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

ADVISOR

Benjamin J. Laugelli, Assistant Professor, Department of Engineering and Society

Introduction

In the early 2000s, the Patriot Missile System unintentionally killed two individuals on impact. Upon investigation, the RAF Board of Inquiry revealed that the autonomous operation of the missile batteries, a protocol for target classification, and the lack of broadcasting of their identification were the primary factors that caused this incident. After this incident, in 2005, a Defense Science Board Task Force required intensive observation of the system's performance and functionality.

A 2012 article attributes the first failure of the Patriot Missile System's major software issues to poor management and assessments, highlighting how automation can bring unforeseen risks (McQuaid, 2012). However, there is scant discussion on the moral decisions made by the system's programmers, likely due to limited transparency about the involved companies. Despite this, extensive data exists on the production process and subsequent changes. During interviews with the program manager, serious data quality issues were discovered, reflecting the accountability challenge in a complex project like this (Mitchell, 2000). Such omissions underscore the problem of many stakeholders and erode the practice of moral responsibility among engineers (Jing, 2020).

Drawing on virtue ethics, the immorality of the programmers' actions will be elucidated by showing their lack of professionalism, safety measures, and proper documentation. Virtue ethics determines the character necessary for a good life (Missilbrook, 2015). In order to shed light on the morality of the programmers’ actions when creating and handling the Patriot Missile System, the arguments presented will be drawn primarily from Kaw's "Round off errors and the Patriot missile" and McQuaid's "Software disasters--understanding the past, to improve the future."

Background

In collaboration with the United States Army, Raytheon developed the Patriot Missile System. A team of unidentified programmers created the AI-based program. This software facilitates communication, command and control, radar surveillance, and missile guidance. In 2003, the system misidentified a U.K. Tornado jet as a missile and shot it down without warning, resulting in the loss of two lives. This incident prompted a review of the program by the RAF Board of Inquiry and the Defense Science Board Task Force, which raised questions about the system's performance and functionality. The primary information regarding this case comes from publicly published articles and cited work. (McQuaid, 2012).

Literature Review

An immense amount of research has assessed the failure of the Patriot Missile System Crisis. The analysis focused primarily on the systemic failure of the system's automation. In particular, they looked at the engagement-control algorithms used in the system's “automatic mode.” When incidents similar to the Patriot Missile System occur, the technical explanation of the software failing is usually due to a critical error with recognition. However, existing research ignores the analytical viewpoint concerning the morality of the programmers' when creating and implementing the Patriot Missile System.

In Science & Global Security, Lewis describes the recollection of the failure of the Patriot Missile System (2000). Lewis highlights that the designers knew how to prevent the failure from occurring yet were unable to prevent it (2000). Lewis notes that the results from the Patriot Missile System vary due to differences in performance assessments and that a uniform performance metric would reduce errors' quantification (Lewis & Postol, 2000). Lewis describes variations amongst this incidence compared to others performed by the Patriot Missile System.

While Lewis denotes the importance of data quantification, he fails to outline the moral judgment of the programmers associated with the failure.

In *Software disasters - understanding the past, to improve the future*, McQuaid highlights the first failure of the Patriot Missile System in 1991 (2012). McQuaid builds upon the characterization that the designers failed to equip the users with proper training and qualifications to use the system for its intended purposes (2012). McQuaid claimed there was a lack of training regarding false targets, and safety-critical software. As a result, this caused a shortened reaction time for the users of the Patriot Missile System to ensure that the system's engagement with the target was precise. Similarly, this meant that the Patriot Missile System users had reduced communication time with the higher-ups.

Consequently, this caused a misuse of the device and the lives of twenty-eight people in Saudi Arabia. He denoted the failure in 1991 as the chief reason for the loss of the two individuals in the U.K. aircraft–which will be highlighted throughout this paper. Like the first article, this focuses on the usage of the actual system as opposed to the moral analysis of the programmers' who created it.

Although McQuaid and Lewis believe a tremendous amount of information needs analysis regarding the characterization of the failure, it is imperative to understand the crisis of the Patriot Missile System from a developmental and moral perspective. The current research narrative defines the incident's root cause as improper engineering practices, failing to acknowledge the programmers' traits and morality that enabled these practices. This paper critiques the practices of the Patriot Missile System programmers and employs a virtue ethics framework to develop a normative judgment of their actions.

Conceptual Framework

The morality of the programmers' actions in the Patriot Missile System can be analyzed using a virtue ethics framework. Virtue ethics is a moral philosophy centered on cultivating virtuous character traits, such as honesty and courage, as the foundation for ethical decision-making (Missilbrook, 2015). It prioritizes the development of individual virtues, aiming for eudaimonia, or human flourishing, as the ultimate goal (van Hooft, 2006). Virtue ethics defines a virtue as the mean between two extremes. As an example, courage is the mean between recklessness and cowardness. For this to occur in an ideal state, a person must be able to quantify and apply moral virtues by various means. For instance, imagine someone who views honesty as a fundamental virtue. In their professional interactions, they must consistently prioritize truthfulness, even when faced with difficult situations such as disclosing mistakes or delivering unfavorable news to stakeholders.

For an action to be morally justifiable, that action must be what a virtuous agent would do in any situation (Darwall, 2005). A virtuous agent is an individual who consistently demonstrates morally commendable behavior and embodies positive virtues. In this case, we analyze the virtues of the programmers of the Patriot Missile System, utilizing Pritchard's view of 'Virtues for Morally Responsible Engineers' (Pritchard, 2001). The virtues used to analyze the actions of the programmers include:

1. Integrity: Upholding honesty, transparency, and consistency.

2. Professionalism: Demonstrating respect, reliability, and accountability.

3. Competence: Striving for excellence in technical skills and knowledge.

4. Ethical Leadership: Leading by example and promoting ethical behavior.

5. Collaboration: Valuing teamwork, cooperation, and inclusivity.

6. Environmental Responsibility: Recognizing the impact of engineering activities on the environment and advocating for sustainable practices that minimize harm.

7. Safety: Prioritizing the safety and well-being of individuals, communities, and the public.

8. Social Justice: Advocating for fairness, equity, and inclusivity in engineering practices.

9. Civic Engagement: Engaging actively in the engineering profession and broader society.

10. Lifelong Learning: Embracing a commitment to continuous learning, reflection, and self-improvement.

Figure 1: Pritchard's view of 'Virtues for Morally Responsible Engineers'

Having all these traits is insufficient to qualify as a morally responsible engineer; however, lacking any of these diminishes responsible engineering practice (van Hooft, 2006). To judge these virtues' abundance or lack thereof, we must return to the definition of virtue (Poel & Royakkers, 2011).

1. Moral Excellence: Virtue is the quality of possessing and practicing moral excellence.
2. Good or Right Action: Virtue entails the inclination and commitment to choose and perform actions that are considered good or right according to ethical standards.
3. Positive Character Traits: Virtue encompasses positive character traits.
4. Habitual Practice: Virtue involves cultivating positive habits and behaviors
5. Aiming for Eudaimonia: In virtue ethics, virtue is associated with pursuing eudaimonia, or human flourishing.

Figure 2: Definition of Virtue

For the simplicity of this paper, it should be assumed that the programmers of the Patriot Missile System have questionable virtues based on inconsistent accounts of the results of the failure. As a result, the following section will analyze a set of decisions made by the programmers based on the three virtues: professionalism, safety, and proper documentation of classification and identification.

Analysis

The programmers in charge of the Patriot Missile System failed to uphold their moral responsibility as engineers. This claim is highlighted when looking at their lack of professionalism, safety, and proper documentation of classification and identification. For clarity, professionalism will be looked at through the lens of accountability. The deliberate steps they made led to the development of the Missile System and the fatal passing of two individuals. It is essential that when engineers are making rational decisions, they are not lacking in virtues and morality. Based on the foundations of being a morally responsible engineer, stating that these programmers are missing these qualities further supports the claim of lacking morality when making rational decisions. Falling short of one of these virtues correlates to being a morally irresponsible engineer - lacking three is inexcusable (Pritchard, 2001). A proper examination of the programmers' actions using a virtue ethics approach can deem them morally irresponsible and not acting as virtuous agents.The argument will be expressed individually by expanding upon the absence of three specific virtues in this situation. Furthermore, it highlights that this failure could have been avoided, yet as engineers, the programmers failed to do so.

Professionalism /Accountability

The first virtue absent in the programmers' actions is a sense of professionalism. Professionalism refers to the responsibility, integrity, and transparency individuals or organizations exhibit in fulfilling their duties and obligations (Steib, 2011). Accountability through a professionalism lens refers to the ethical and responsible behavior expected from individuals within a professional context (Steib, 2011). When looking at the failure of the programmers' ability to show professionalism and accountability, it is essential to describe the extent of the Patriot Missile System's developmental failure more intricately. The Patriot Missile System was programmed in a manner in which information was translated into digital signs, symbols, and images (Kaw, 2008). The Patriot Missile System was intended to categorize objects into patterns and time. When this principle is applied on its own, it is acceptable. But when this principle is combined with a system that should be able to distinguish objects regardless of how similar they may be, it guarantees failure to occur.

A problem a system with a simplistic categorization of objects can run into is that an unidentified object that looks similar in size or shape to an object identified as a threat may be misconfigured based on the system's memory and adaptations. Because the system only has training based on related objects, it is impossible to know what decisions could be made regarding objects because it will always be limited (Peoples, 2008). For example, let us assume a balloon shaped like a missile traveling at the speed of light is hurling toward the Patriot Missile System; due to the system's limited recognition, it will be shot out of the sky almost instantaneously. Typically, safeguards are written as a countermeasure, ensuring that incidents like this are minimized. However, this system lacked this principle.

It is essential to state the importance of professionalism, as it is fundamental to system recognition. Most system failures are detected through testing of pattern recognition (Pau, 1981). These failures are produced when there is an invalid linkage between image recognition and actions taken. Given the variability in such incorrect linkages, relying solely on systemic testing will not suffice to validate the proper sequence the system calculates. A system without strict pattern recognition will work repeatedly until a failure occurs (Blumberg, 2017).

The critical question is, why is the failure of the Patriot Missile System so significant? The programmers allowed the system to be written with code to integrate simple pattern recognition without considering flexibility and modularity for adaptation (Chen, 2012). Flexibility and modularity for adaptation in the Patriot Missile System refer to its ability to adjust and evolve to meet changing requirements and threats (Chen, 2012). For instance, being quicker in quantifying threats. The redaction of flexibility and modulation is a massive aphesis. This expunction lies in the outcomes of two situations: a safer and just system and a system that lacks. Whether or not the programmers recognized the importance of this integration, they still managed to implement it into the system. The implementation process reflects poorly on their commitment to professionalism, revealing a lack of competence.

Professionalism is the ability to hold professional competence. Accountability is one of the abilities to be qualified as a moral and just engineer who displays professionalism (Luke & Modrow, 1982). If the programmers could not recognize the importance of flexibility and modularity for system adaptation, they lacked adherent intelligence and did not uphold a sense of professionalism. Nevertheless, if they knew of the consequences of including this attribute but willingly decided not to follow through, they acted recklessly. In this situation, the programmers acted recklessly and unprofessionally by creating a simplistic system based on simple regularities incapable of specifying objects. Regardless of their rationale for this simplistic system, their actions are inexcusable and highlight their incompetence in handling such high-level professional engineering.

Many may hold the opinion that if the programmers genuinely lacked the knowledge to add flexibility and modularity to the system, it is not truly unprofessionalism but rather a lack of competence. Seemingly, some believe it may be farfetched to judge the character of individuals who only acted based on what they knew and to the highest degree of what they deemed their work to be. However, competence does not necessitate knowing everything about one's profession; competence implies recognizing when one lacks knowledge (Leo, 1999). Even though competence does not equate to knowing everything relative to one's field, the engineering code of conduct states, "Engineers shall undertake assignments only when qualified by education or experience in the specific technical fields involved" (NSPE, 2002).

As previously stated, the key takeaway from the engineering code of conduct is that engineers are required to take on assignments that are not beyond their qualifications. When engineers produce a product that fails, they are likely working beyond their qualifications and means. The programmers assigned to the Patriot Missile System acted beyond their qualifications by creating a system that lacked the total capacity to handle every situation that could transpire. The figure below depicts how the system interacts with objects based on conflicts. As seen here, from peace to insurgency to general war, all air defense requirements had the same metric of friendly C2. Friendly C2 is the military strategy that implements information warfare (IW) on the battlefield based on command and control warfare (Hutcherson, 1994). This strategy shows how the system functions in regard to any threats. The functionality of the system, however, remains the same in all three situations regardless of threats. Consequently, the rigidity of the Patriot Missile System can result in costly delays, both in terms of time and lives (Hutcherson, 1994). This Friendly C2 feature is generically classified and falls into the same category as simple regularities, undermining their obligation to create a definite system in every aspect.

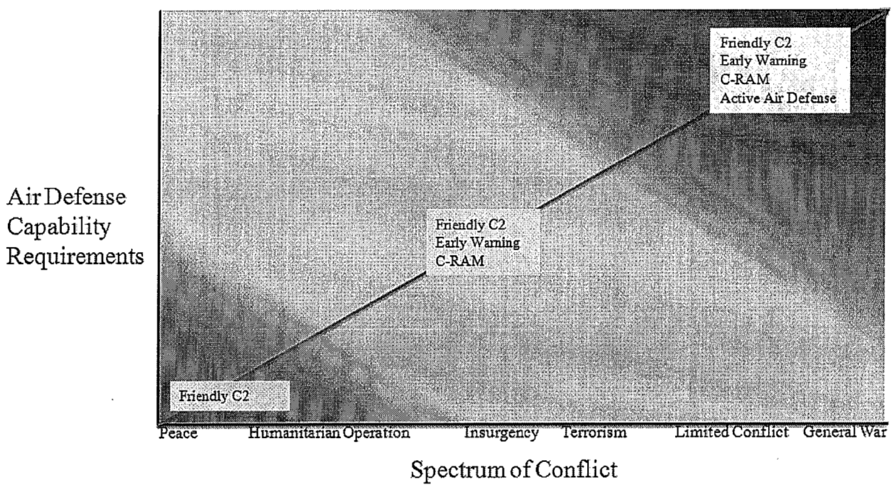

*Figure 3: Air Defense Capability Requirements across the Full Spectrum of Conflict (*Costello, M. (2009).

Furthermore, the programmers of the Patriot Missile System exhibited incompetence not only by creating a system that was too rigid but also by venturing into a project that surpassed the boundaries of their expertise. The inability to apply a detrimental principle such as qualitative protocol depicts a flaw in the programmers' rationale when making decisions. Qualitative protocol comprises criteria for evaluating the Patriot Missile System's performance, reliability, and effectiveness across different operational scenarios (Hutcherson, 1994). The usage of this protocol would ensure the Patriot Missile System meets the operational requirements of its users and remains a reliable and effective defense asset. This critical flaw supports the claim that the programmers worked far outside their bounds and lacked the virtue to commit to professionalism.

Safety

The second virtue absent in the programmers' actions is the usage of safety. Safety ensures that the well-being of individuals, communities, and the public is held to the highest degree (van Gelder et al., 2021). Meyer and Zack describe the dynamic method in which informational products are built as requiring a complex synthesis of “data, information and knowledge” (1996). Applying the method by which informational products are built ensures that hazards can be avoided instead of integrated. According to the Code of Ethics for Engineers cited in the NSPE, "Engineers, in the fulfillment of their professional duties, shall hold paramount the safety, health, and welfare of the public." (2002). The word 'paramount' emphasizes that as engineers, our highest priority is ensuring the safety of the public. The programmers failed to implement the paramount duty as engineers when they created a system that failed the United Kingdom, the United States, and the two individuals who were unfortunately killed.

The Patriot Missile System was designed to analyze fast-moving objects and indicate the threat and severity of those objects (Kaw, 2008). This functionality should be relatively easy for the Patriot Missile System to produce, yet it ended in a tragic event. According to the Defense Technical Information Center (DFIC), this is not the first time we have seen errors occur with the system (1992). This is a massive problem given that the U.S. now owns and functions three systems similar to the original. In 1991, a Patriot Missile System in Dhahran, Saudi Arabia, failed to intercept an incoming Scud missile, resulting in the death of 28 Americans. Responding to Representative Wolpe's request, the General Accounting Office (GAO) investigated the incident to determine if a software problem was involved (Patriot Missile Defense: Software Problem Led to System Failure at Dhahran, Saudi Arabia, 1992). The investigation revealed that a software issue caused inaccurate tracking calculations. This was worsened by the system's continuous operation for over 100 hours, ultimately leading to the failure to intercept the Scud missile (Patriot Missile Defense: Software Problem Led to System Failure at Dhahran, Saudi Arabia, 1992). The figure below highlights the claim that the programmers failed to act virtuously in terms of safety. This figure shows that the longer the system runs, the greater the inaccuracy. When the system was run for 100 hours, it had the highest inaccuracy at 0.3433 seconds. This account shows that not only were the programmers aware of their initial failures, but they also failed to fix this software and systemic issues, which could have prevented more loss of life.

Hours	Seconds	Calculated Time (Seconds)	Inaccuracy (Seconds)	Approximate Shift in Range Gate (Meters)
0	0	0	0	0
1	3600	3599.9966	.0034	7
8	28800	28799.9725	.0275	55
20[a]	72000	71999.9313	.0687	137
48	172800	172799.8352	.1648	330
72	259200	259199.7528	.2472	494
100[b]	360000	359999.6667	.3433	687

[a]Continuous operation exceeding about 20 hours—target outside range gate

[b]Alpha Battery ran continuously for about 100 hours

Figure 4: Table of Quantification of Hours run to Inaccuracy of System (Patriot Missile Defense: Software Problem Led to System Failure at Dhahran, Saudi Arabia, 1992)

In the first design of the Patriot Missile System, data interpolation was not developed into the system (Patriot Missile Defense: Software Problem Led to System Failure at Dhahran, Saudi Arabia, 1992). Data interpolation is the ability of a system to calculate unknown parameters, such as the speed and time of a missile (Talbot, 2005). The programmers' fault was not equipping the system with the necessary data encoding for metrics such as time, speed, and size, resulting in its inability to encode them properly. The flaw in not including this is double-sided. First, the initial Patriot Missile System did not have the proper integration needed to be fully functional and used by the government as a safeguard. Secondly, the functionality of the first rendition of the Patriot Missile System in 1991 and the system used in 2003 have the same integrated countermeasures and functions (Talbot, 2005). Reusing the same modules poses a risk of errors occurring, with the added challenge of being unable to quantify the potential severity of these errors. This means the inaccuracy in 1991 was still present when the Patriot Missile System was used again in 2003. The decision by the programmers not to revise the code after the fault in 1991 goes against engineering principles of prioritizing safety and human life.

Though it is impossible to fault the programmers alone for this decision regarding reusing the modules of code, they had a moral obligation to ensure that all issues that occurred the first time would be rectified when using the code again. By choosing not to do so, they lacked the means to ensure safety barriers were met and demeaned their vow to the engineering code of conduct. There is no situation where this case would ever be excusable when safety is fundamental to engineering principles. This failure highlights the programmers' lack of commitment to safety in relation to virtue ethics.

<u>Improper documentation of classification and identification</u>

The third virtue absent in the programmers' actions is the use of proper documentation of classification and identification. Proper documentation of classification and identification ensures the reproducibility of a system's intended usage (Alfano, 2013). The correct manner to produce documentation of classification and identification is to compile complete records, ensure discrepancies do not occur, and ensure security protocols (Patel & Chotai, 2011). Multiple failures of the Patriot Missile System indicate that there should have been more documentation and identification of systemic issues. After failures occurred, the programmers failed to produce proper documentation and accurately account for identification.

During the U.S. General Accounting Office's initial scrutiny of the system, it assessed the defense missile system's human factors during Operational Test II (1992). Interviews with select participants were aimed to identify concerns about troop proficiency trainer programs, maintenance operations, and procedures. Human factors is a multidisciplinary field that focuses on understanding the interactions between humans and the systems, products, environments, or processes they interact with (Carter & Lockhart, 1982). Human factors were found in each subsystem, primarily focusing on software, troop proficiency trainers, equipment publications, missile reload, engagement control station and information coordination central environments, and maintenance (Patriot Missile Defense: Software Problem Led to System Failure at Dhahran, Saudi Arabia, 1992). The results informed decision-making for the system's production by the Army and Defense Systems Acquisition Review Councils (Carter & Lockhart, 1982).

The documentation concerning the programmers' code indicated the need for improvement (Carter & Lockhart, 1982). The figure below highlights the assertion that the programmers' code required enhancement. This figure illustrates the estimated budget for the defense system in 1992 following the failure in 1991. Two systems, the TOW and AAWS-M, had their budgets significantly reduced to allocate more funds to the Patriot Missile System. Consequently, this elevated the Patriot Missile System to the status of the most expensive program funded by the United States. The budget increase aimed to enhance the software, refine missile training, and improve training efficiency.

Dollars in millions

Missile system	Fiscal year 1992	Fiscal year 1991	Fiscal year 1990	Total
Patriot	$24.3	$8.0	$0	**$32.3**
Stinger	11.3	0	2.0	**13.3**
Hellfire	19.7	0	0	**19.7**
TOW	0[a]	11.0[b]	0	**11.0**
MLRS	5.1[c]	0	0	**5.1**
ATACMS	4.4	0	0	**4.4**
AAWS-M	0	4.4	0	**4.4**
Total	**$64.8**	**$23.4**	**$2.0**	**$90.2**

Figure 5: Potential Reductions and Rescissions to Army Missile Programs(*1992 army budget: Potential reductions to missile programs*, 1991)

Although it was primarily their manager's fault, the programmers are ethically and morally bound to ensure proper documentation and account for true identification post-failure (McQuaid, 2012). The lack of these safeguards led to a system failure, which caused the tragic loss of lives. The lack of documentation from the programmers was not merely a procedural oversight but a deficiency in virtue. It was starkly evident from the findings that "preliminary results indicate that Patriot training remains inadequate to prepare operators for complex Patriot engagements." (Patriot advanced capability-3, n.d).

The programmers' inability to produce documentation on the system's operation led to preliminary results indicating inadequate training for preparing operators for complex engagements with the Patriot Missile System. This inadequacy of preparation can be traced back to the paucity of documentation within the operational guidelines of the Patriot Missile System. For instance, a manual that expands the functionality of several engagements of the Patriot Missile System with targets would have been crucial knowledge for the operators to know.

Similarly, because the programmers withheld crucial documentation, performing manual overrides of the Patriot Missile System would be more complex.

Furthermore, the programmers' failure to provide comprehensive documentation compromised the functionality of the metrics essential for ensuring the system's efficacy. (Patriot Advanced Capability-3 [PAC-3], n.d.). By failing to be thorough and meticulous in their documentation practices, the programmers inadvertently undermined the readiness and effectiveness of the Patriot Missile Systems. This absence of proper documentation practices not only hindered the operators' ability to navigate complex engagements but also jeopardized the overall reliability and functionality of the system itself. A deficiency in thoroughness and meticulousness in their documentation practices underscores the critical importance of virtue, not only in technical proficiency, but also in the conscientious execution of duties and responsibilities within the realm of professional practice.

Improper documentation of the actions of the system post-failure diminished the oath we are bound to as morally sound engineers (McQuaid, 2012). Failing to produce proper documentation diminishes the training individuals would have on the meaning of their code for system interaction, and protocols when troubleshooting the system. Although their work may seem easy to follow to the programmers, it would be highly confusing to someone who may not work in their field. Continuous training and documentation is the only way engineering safety can be guaranteed to the highest degree (van Gelder et al., 2021).

Detail is essential when creating a complex system like the Patriot Missile System. Any action that does not prioritize detail diminishes moral engineering ethics. The Patriot Missile System programmers disregarded and lacked the virtues of proper documentation of classification and identification, when it came to the operation of the Patriot Missile System.

Conclusion

Regardless of the minimal information known about the identity of the programmers of the Patriot Missile System, it is justifiable to rationalize the actions and character of the programmers based on the decisions they made throughout the years the system was being used. The decisions are critical to illuminating failures regarding the three virtues expanded on that exemplify a morally responsible engineer. These programmers lacked the virtues of professionalism, safety, and proper documentation of classification and identification. Using a virtue ethics framework, the actions of the programmers can be concluded to be not immoral.

While it is essential to understand why and how the Patriot Missile System failed, it is also necessary to critique its foundational composition through a virtue ethics lens that depicts the programmers' actions as moral or immoral. The examples displayed throughout this paper show that the lens through which the Patriot Missile System was viewed was primarily the perspective that the failures occurred in how the system interacted with humans, compiled data, and performed actions. Yet, this dismisses the immoral decisions made by the programmers.

This argument serves as a vital framework for engineers to comprehend the significance of character qualification when engaging in engineering actions and devising production solutions. Specifically, it sheds light on the detrimental outcomes that arise when lapses in character manifest in these engineering endeavors. By examining the repercussions of such lapses, engineers gain insight into the essential role of character in shaping not only the technical aspects but also the ethical dimensions of their work. As engineers, we must be held accountable for the safety and well-being of people, especially those who use or come in contact with our designs. Using virtues keeps us accountable for everything we do and upholds the values we are sworn to adhere to. Critiquing our decisions and designs using these virtues allows us to create safer designs that incorporate everyone and everything into them despite the complexity of the designs.

References

Alfano, M. (2013). Identifying and defending the hard core of virtue ethics. *Journal of Philosophical Research*, *38*, 233–260. https://doi.org/10.5840/jpr20133812

Blumberg, M. (2017). The value and limitations of pattern recognition. *Startup Ceo*.https://startupceo.com/2017/08/the-value-and-limitations-of-pattern-recognition

Carter, M., & Lockhart, J. (1982). *Human factors evaluation of the patriot air—Defense missile system during operational test II* (Report No. 1335). Defense Technical Information Center. https://apps.dtic.mil/sti/citations/ADA138837

Chen, C., Brown, D., Sconyers, C., Zhang, B., Vachtsevanos, G., & Orchard, M. E. (2012). An integrated architecture for fault diagnosis and failure prognosis of complex engineering systems. *Expert Systems with Applications*, *39*(10), 9031–9040. https://doi.org/10.1016/j.eswa.2012.02.050

Costello, M. (2009). *Capability gaps caused by army modularity: A need for air defense at the tactical level.* Defense Technical Information Center. https://apps.dtic.mil/sti/pdfs/ADA510316.pdf

Darwall, S. (2005). Virtue ethics. *Australasian Journal of Philosophy*, *83*(4), 589–597. https://doi.org/10.1080/00048400500339003

Hutcherson, N. (1994) . *Command and control warfare putting another tool in the war-fighter's Database.* Defense Technical Information Center. https://apps.dtic.mil/sti/pdfs/ADA286005.pdf

Jing, S., & Doorn, N. (2020). Engineers' moral responsibility: A confucian perspective. *Science and Engineering Ethics*, *26*(1), 233–253. https://doi.org/10.1007/s11948-019-00093-4

Kaw, A. (2008). Round off errors and the patriot missile. *The Numerical Methods Guy*.

https://autarkaw.wordpress.com/2008/06/02/round-off-errors-and-the-patriot-missile/

Leo, R. J. (1999). Competency and the capacity to make treatment decisions: A primer for primary care physicians. *The Primary Care Companion for CNS Disorders*, *1*(5), 1-11. https://doi.org/10.4088/PCC.v01n0501

Lewis, G. N., & Postol, T. A. (2000). Technical debate over patriot performance in the gulf war: American physical society panel correctly rejects criticisms of analysis showing patriot failed to destroy scud warheads. *Science & Global Security*, *8*(3), 357–398. https://doi.org/10.1080/08929880008426482

Luke, R. D., & Modrow, R. E. (1982). Professionalism, accountability and peer review. *Health Services Research*, *17*(2), 113–123.

McQuaid, P. A. (2012). Software disasters—Understanding the past, to improve the future. *Journal of Software: Evolution and Process*, *24*(5), 459–470. https://doi.org/10.1002/smr.500

Meyer, M., & Zack, M. (1996). The design and development of information products. *MIT Sloan Management Review*, *21*(1), 1–2.

Misselbrook, D. (2015). Virtue ethics – an old answer to a new dilemma? Part 1. Problems with contemporary medical ethics. *Journal of the Royal Society of Medicine*, *108*(2), 53–56. https://doi.org/10.1177/0141076814563367

Mitchell, G. R. (2000). Placebo defense: Operation desert mirage? The rhetoric of patriot missile accuracy in the 1991 Persian Gulf War. *Quarterly Journal of Speech*, *86*(2), 121–145. https://doi.org/10.1080/00335630009384286

National Society Of Professional Engineers. (2002). *National Society of Professional Engineers NSPE*.

Patel, K. T., & Chotai, N. P. (2011). Documentation and records: Harmonized GMP requirements. *Journal of Young Pharmacists*, *3*(2), 138–150. https://doi.org/10.4103/0975-1483.80303

Patriot advanced capability-3 (pp. 175–179). (n.d.). https://www.dote.osd.mil/Portals/97/pub/reports/FY2016/army/2016patriot.pdf?ver=201-08-22-105407-280

Patriot Missile Defense: Software problem led to system failure at Dhahran, Saudi Arabia (Report no. GAO/IMTEC-92-26). (1992). U.S. General Accounting Office, GAO, Washington, DC 20548. https://apps.dtic.mil/sti/pdfs/ADA344865.pdf

Pau, L. F. (1981). Application of pattern recognition to failure analysis and diagnosis. In J. Rasmussen & W. B. Rouse (Eds.), *Human Detection and Diagnosis of System Failures* (pp. 389–409). Springer US. https://doi.org/10.1007/978-1-4615-9230-3_25

Peoples, C. (2008). Decoding ballistic missile defense: Semiotics and the power of the image in American Ballistic Missile Defense. *Social Semiotics*, *18*(1), 17–31. https://doi.org/10.1080/10350330701838852

Poel, I. van de, & Royakkers, L. M. M. (2011). *Ethics, Technology, and Engineering: An Introduction*. Wiley-Blackwell.

Pritchard, M. S. (2001). Responsible engineering: The importance of character and imagination. *Science and Engineering Ethics*, *7*(3), 391–402. https://doi.org/10.1007/s11948-001-0061-3

Stieb, J. A. (2011). Understanding engineering professionalism: A reflection on the rights of engineers. *Science and Engineering Ethics*, *17*(1), 149–169. https://doi.org/10.1007/s11948-009-9166-x

Talbot, D. (2005). Preventing “fratricide.” *MIT Technology Review*, *108*(6), 39–40.

Van Gelder, P., Klaassen, P., Taebi, B., Walhout, B., Van Ommen, R., Van De Poel, I., Robaey, Z., Asveld, L., Balkenende, R., Hollmann, F., Van Kampen, E. J., Khakzad, N., Krebbers, R., De Lange, J., Pieters, W., Terwel, K., Visser, E., Van Der Werff, T., & Jung, D. (2021). Safe-by-design in engineering: An overview and comparative analysis of engineering disciplines. *International Journal of Environmental Research and Public Health*, *18*(12), 6329. https://doi.org/10.3390/ijerph18126329

Van Hooft, S. (2014). *Understanding virtue ethics* (1st ed.). Routledge. https://doi.org/10.4324/9781315712130

1992 Army budget: Potential reductions to missile programs (Report no. GAO. NSIAD-91-320BR). (1991). United States General Accounting Office Washington, D.C. 20548. https://apps.dtic.mil/sti/pdfs/ADA253470.pdf