The Failure of the Mars Climate Orbiter Through the Lens of Virtue Ethics

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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

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Introduction

In December of 1998, the Mars Climate Orbiter was launched from Cape Canaveral Florida. The Orbiter was designed to monitor dust and water vapor presence on Mars, and take daily pictures to observe potential climate changes occurring on Mars. On September 23rd, 1999, the Orbiter attempted to begin its orbit of Mars. However, due to unit errors in the commands being sent to the Orbiter, the satellite missed orbit by roughly 90 miles, and eventually was destroyed by atmospheric pressure. This was a massive failure for NASA, and revealed many issues with management and protocols that allowed for such a simple mistake to happen.

The cause of the Orbiter's failure, that being the mismatch of units between NASA and the contractor Lockheed Martin, is well documented and has been thoroughly explored by both NASA administration as well as outside scholars. In contrast, there exists little documentation on the morality of the software developers who were responsible for this mistake, nor is there much on the other factors that led to this failure. By not focusing on these aspects of the failure, NASA administrators, and scholars everywhere studying this incident, fail to see a huge aspect of the failure, and miss out on ethical elements of software development.

I believe that by analyzing the Mars Climate Orbiter through the ethical framework of virtue ethics, it will demonstrate how the software developers acted unacceptably. Virtue ethics focuses on specific qualities, behaviors, and characteristics that make one a virtuous software engineer. By showing how the software engineers failed to practice the specific virtues of "ability to communicate clearly and informatively", "striving for quality", and "professionalism", it will become clear how the software developers acted immorally. I will analyze accounts from both NASA administrators as well as outside scholars to prove how these virtues were not upheld by these developers. This will include reports shortly after the incident, as well as thorough examinations that were written years later.

Background

The Mars Climate Orbiter was part of a larger program to investigate Martian climate, atmosphere, surface level changes, and other aspects of Mars. Due to the large costs associated with the International Space Station, as well as the recent loss of Mars Observer, smaller projects like the Mars Climate Orbiter were given priority. This was part of NASA's new "better, faster, cheaper" mentality. "Better, faster, cheaper" meant that NASA was pushing out smaller projects like the Mars Climate Orbiter at an unprecedented rate, in the hopes that most would be successes. The construction of the spacecraft was given to Lockheed Martin. Lockheed Martin describes themselves as "a global security and aerospace company that employs approximately 116,000 people worldwide and is principally engaged in the research, design, development, manufacture, integration and sustainment of advanced technology systems, products and services". The total cost of the failed mission was $327.6 million dollars. Thankfully, because this was an unmanned mission, no lives were lost (unlike many of NASA's other infamous failures).

Literature Review

There is a plethora of documentation, research papers, and analyses of the causes of the failure of the Mars Climate Orbiter. One of the best sources to analyze the common way of understanding this failure is the "Mars Climate Orbiter Mishap Investigation Board Phase I Report" which was produced by the Mars Climate Orbiter Mishap Investigation Board in 2000. The report notes that, "The MCO MIB has determined that the root cause for the loss of the Mars

Climate Orbiter spacecraft was the failure to use metric units in the coding of a ground software file, “Small Forces,” used in trajectory models” (p. 6). This seems to be the standard way of reporting the cause of the failure across many scholarly sources. However, the MCO MIB goes one step further than many and goes on to list 8 other contributing causes, shown in Figure 1.

Contributing Causes:
1. Undetected mismodeling of spacecraft velocity changes
2. Navigation Team unfamiliar with spacecraft
3. Trajectory correction maneuver number 5 not performed
4. System engineering process did not adequately address transition from development to operations
5. Inadequate communications between project elements
6. Inadequate operations Navigation Team staffing
7. Inadequate training
8. Verification and validation process did not adequately address ground software

Figure 1: Other Contributing Causes

While the causes listed are important, the MCO MIB does not address the immoral actions of the developers, which are just as important. The MCO MIB, like the following literature, places a brunt of the blame on the managers and the systems in place, rather than the engineers themselves.

“Why projects fail? How contingency theory can provide new insights – A comparative analysis of NASA’s Mars Climate Orbiter loss” offers a different, more unique perspective on the failure of the Mars Climate Orbiter. Instead of focusing on the technical aspects that led to the failure, Sauser et al. focus on the managerial failures, saying “in many cases the root cause of the failure is not technical, but managerial” (p. 665). The authors use three distinct frameworks to argue that “the constraints imposed on them under the policy of ‘better, faster, cheaper’, led the program to its inevitable failure” (Sauser et al., p. 655, 2009). While this approach does raise more questions about immoral behavior than the MCO MIB report did, it still fails to argue that the developers themselves acted immorally, instead placing all of the blame on managers in general.

A rather insightful way to try to analyze the Mars Climate Orbiter failure was written by Nancy Levenson. In her paper, Systemic Factors in Software-Related Spacecraft Accidents (2004), Levenson looks at 4 separate spacecraft accidents where software can be blamed for the failure. By attempting to find commonalities between the incidents, Levenson hopes to find specific factors present across the accidents that are more likely to cause accidents, and to evaluate a new type of accident model. Many of the factors that she reports are similar to those identified by both the MCO MIB and by Sauser et al. These include managerial issues such as a flawed review process as well as issues with the software itself. Unlike the former two pieces of literature, however, Levenson does attempt to dig into the problems with the engineers themselves. Some of her points, such as “Software Reuse without Appropriate Analysis of its Safety” (Levenson, 2004, p. 13) and “Limited Communication Channels and Poor Information Flow” (Levenson, 2004, p. 9) attempt to point at issues that this paper will consider violations of necessary virtues. However, Levenson does not place any particular importance on these issues, and she, like Sauser et al., seems to taking a stance that blames management more than the engineers. My analysis will work to fill in the gaps that these pieces of literature fail to account for, by viewing this accident through the lens of virtue ethics.

Conceptual Framework

While the authors of “Why projects fail?” used three different frameworks focused on management to make their argument, my analysis instead draws on the virtue ethics framework, which allows me to analyze the morality of the software developers, and how it inevitably led to failure. In their chapter on Virtue Ethics, van de Poel and Royakkers describes virtue ethics as, "an ethical theory that focuses on the nature of the acting person. This theory indicates which good or desirable characteristics people should have or develop to be normal" (2011, p. 95).

Aristotle was the first to coin the term virtue ethics, and believed that the highest goal of a human is to strive for *eudaimonia*, or "the good life". In order to strive for this, we must perform virtuous activities. In Aristotle's view, it was of utmost importance to strive to be in the middle of two extremes, in almost everything in life. Using Aristotle's logic, van de Poel and Royakkers note that, "a moral virtue is the middle course between two extremes of evil; courage is balanced between cowardice and recklessness for example" (2011, p. 97). However, even Aristotle recognized that this is a hard line to tow, and that the lines can shift, and thus a person must use his wisdom to judge how he should act in any given situation.

While these ideas of moral virtues are nice and rather simple, it is difficult to map them directly to engineering and software development jobs. Michael Pritchard intended to succeed in mapping the virtues to Virtues for Morally Responsible Engineers, recreated in the list below (Pritchard, 2001).

Virtues for Morally Responsible Engineers

- **Expertise / professionalism;**
- **Clear and informative communication;**
- **Cooperation;**
- **Willingness to make compromises;**
- **Objectivity;**
- **Being open to criticism;**

- **Stamina;**
- **Creativity;**
- **Striving for quality;**
- **Having an eye for detail; and**
- **Being in the habit of reporting your work carefully.**

I will be using his list of virtues to judge whether the members of NASA and Lockheed Martin acted in a moral and virtuous manner or not. While Pritchard created this list to show what virtues are necessary for engineers, he admitted that, “However, it is conceivable that an engineer could have all of the dispositions in this … group and still be dedicated to any number of morally reprehensible engineering projects” (Pritchard, 2001, p. 395). However, he also realized that, “lacking them detracts from responsible engineering practice in general, and exemplary practice in particular” (Pritchard, 2001, p. 395). Thus, I must only prove that the developers lack one or more of the virtues listed above in order to prove that they acted immorally.

Drawing on this virtue ethics framework, I will demonstrate how the engineers and developers of the Mars Climate Orbiter fail to practice the virtues defined by Pritchard of “ability to communicate clearly and informatively”, “striving for quality”, and “professionalism”. By showing how the engineers failed to uphold the virtues central to the virtue ethics framework, I will illustrate how the engineers acted immorally.

Analysis

I will now analyze the Mars Climate Orbiter through the ethical framework of virtue ethics, explained in the conceptual framework section earlier, making it clear how the software developers acted immorally and unacceptably. As mentioned earlier, Pritchard states that missing even one of his listed virtues is enough to detract from a responsible engineer. In showing that the engineers failed to practice the specific virtues of “ability to communicate clearly and informatively”, “striving for quality”, and “professionalism”, it will become clear how the engineers acted immorally.

Ability to Communicate Clearly and Informatively

Perhaps the clearest to see, the ability to communicate clearly and informatively is essential to engineering, but in this setting, I argue that the engineers did not practice this virtue. Communication is “a process by which information is exchanged between individuals through a common system of symbols, signs, or behavior” (Merriam-Webster, 2023). Nearly every source mentioned thus far has mentioned to degree or another how the complete breakdown of communication was a major factor in the failure of the Mars Climate Orbiter. It’s as simple as seeing that the entire unit measurement system for engineers working on the same project was not correctly established, leading to grossly inaccurate calculations and the destruction of the Mars Climate Orbiter. The MCO MIB report stated that “It was clear that the operations navigation team did not communicate their trajectory concerns effectively to the spacecraft operations team or project management” (p. 22). Likewise, Sauser et al. suggest that “For MCO, communication between project elements was perceived by most to be inadequate.” (p. 673). These two reports tell the reader that communication was an important issue throughout the projects development, with indications that it was perhaps a cause of the failure.

However, in both these statements, it seems that they are placing a heavy emphasis on the communication channels themselves (a managerial issue), rather than on the engineers. According to Pritchard’s virtue, it is the duty of the engineer to have the “ability to communicate clearly and informatively”. It is on the onus of the engineer to ensure that they are able to communicate their ideas and understand the ideas of others, and if they don’t understand, communicate that misunderstanding. These sources clearly illustrate that the lack of communication was the defining reason for the failure of the Mars Climate Orbiter, and the engineers were to blame for that lack of communication.

Striving For Quality

Another virtue which the engineers failed to uphold is striving for quality. Quality in terms of an engineering product, is, a “degree of excellence” (Merriam-Webster, 2023). An example of disregard for this virtue is illustrated with the operations navigation team. It is nearly impossible for an engineer to instantly become acquainted with software they have never seen before, did not write themselves, and never tested. Despite this, “The operations navigation team came onboard shortly before launch and did not participate in any of the testing of the ground software” (MCO Report, pg. 19). Testing is an integral part of software development and a key to success, but this report shows that the team that would use the software was completely removed from the testing aspect. Additionally, the operations navigation team was not involved in any step of the design or design review processes.

Likewise, one cannot expect quality when short staffed. The quality of a project is the sum of the backgrounds, efforts, and ideas of all group members. When your group is significantly understaffed, it should be a huge alarm. Yet one of the major reasons for the failure of the Mars Climate Orbiter that the MIB came up with was that they “found that the staffing of the operations navigation team was less than adequate” (MCO Report, p. 23).

Another fundamental aspect of quality is striving for safety. In the case of the Mars Climate Orbiter, “The engineers were challenged to "prove it ISN'T safe," when every dictum of sound flight safety teaches that safety is a quality that must be established--and reestablished under new conditions--by sound analysis of all hazard” (Oberg, 2000). It is nearly impossible to determine that something is failure proof, which the engineers here were tasked with. This is a clear disregard for industry standards and represents a clear lack of morality by both the managers of the project as well as the engineers.

As I have argued, this behavior represents a disregard for the virtue of striving for quality. Some scholars, such as Sauser et al., argue that it is the manager’s responsibility for this failure, but their argument fails to account for the engineer’s responsibility. For it is the engineer’s moral duty to act virtuously, even when told by managers that they don’t need to. There are reports of engineers who realized the immoral behavior going on, but eventually caved and did not stand up against it. One such example is “’Take off your engineering hat and put on your management hat’ was the advice given to one wavering worker, who eventually went along with the launch decision” (Oberg, 2000). By eventually caving to this behavior, the engineer in this example clearly did not uphold the virtue of striving for quality.

Professionalism

The final virtue that I will prove the engineers did not uphold is professionalism. Professionalism is “the conduct, aims, or qualities that characterize or mark a profession or a professional person” (Merriam-Webster, 2023). All virtuous engineers should be fully equipped and qualified for whatever job/task they are given. It is the duty of engineers to communicate if they are not qualified for any given task.

The National Society of Professional Engineer's states that: "Engineers shall not affix their signatures to any plans or documents dealing with subject matter in which they lack competence, nor to any plan or document not prepared under their direction and control." (2017). This policy is in place to ensure that engineers are knowledgeable enough to produce competent work on projects they are involved in. Likewise, the MCO MIB states that the Mission Success First NASA policy, it demands that "every individual on the program/project team continuously employ solid engineering and scientific discipline, take personal ownership for their product development efforts and continuously manage risk in order to design, develop and deliver robust systems capable of supporting all mission scenarios." (MCO MIB, 2000, p. 7).

That is why it is so shocking that the MCO MIB concludes that, "This team's inexperience was a key factor in the root cause of the mission failure." (MCO MIB, 2000, p. 18). Teams will inevitably have some inexperienced members on them, but the entire team lacking the necessary experience, which was the case here, is a recipe for disaster. While they tend to place the blame for this on the managers of the project and the lack of training (which the manager's would presumably be prescribing), saying things such as "This problem might have been uncovered with proper training." (MCO MIB, 2000, p. 18), this attitude fails to account for the engineer's responsibility to know their limitations, which the MCO MIB mentioned 11 pages earlier. Likewise, the MCO MIB also conclude that, in future projects, NASA needs to "ensure that the systems engineering team possesses the skills to fully engage the subsystem engineers so that a healthy communication flow is present up and down the project elements." (MCO MIB, 2000, p. 17). Many scholars attribute the failure to the lack of systems engineers, such as "targeted increases in staffing for systems engineering and several other groups could have mitigated some contributing factors to the MPL failure" (Euler et al., 2001, p. 22). However, this is a dangerous conclusion to draw, as it removes all responsibility on the limited staff to act professionally and report their lack of knowledge and manpower to complete the project in a quality way.

Conclusion

While we should not understate the powerful impact that the software error had on causing the failure of the Mars Climate Orbital, we must also consider the role of the engineers behind the software, and whether or not that were acting virtuous while designing and creating the MCO. Virtue Ethics is a powerful framework by which to argue whether engineers act morally or immorally. van de Poel and Royakkers describe it as "an ethical theory that focuses on the nature of the acting person. This theory indicates which good or desirable characteristics people should have or develop to be normal" (2011, p. 95). Virtues are important for all engineers to uphold, and Pritchard said that ""lacking them detracts from responsible engineering practice in general, and exemplary practice in particular" (2001, p. 395). By observing the failure through the lens of the virtue ethics framework, I argue that the engineers did in fact act immorally, and should be held responsible for this immoral behavior. The engineers clearly failed to practice three different virtues that are required to be moral engineers. These virtues were ability to communicate clearly and informatively, striving for quality, and professionalism. By showing that these engineers failed to uphold any virtues, let alone three like I demonstrated earlier, I have proven that the engineers acted immorally when creating the Mars Climate Orbiter. The failure of the engineers to uphold these virtues directly led to the failure and destruction of the Mars Climate Orbiter.

I believe that it is important to consider this point, as understanding this failure of such a massive scale is important to understanding the ethics of software engineering in general. By not considering the ethics of the engineers themselves and only focusing on the different units being used, people studying this accident fail to see a huge aspect of the failure, and miss out on ethical elements of software development. It could also be used to help to change the policies that the managers make and that the engineers must follow. For instance, the MPL recommendations in the MCO MIB report would likely be altered if this argument was considered. All software engineers must act virtuously at all times, for even the smallest slip ups of immorality can lead to massive system failures.

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