1. Introduction
A typical course in Engineering Ethics consists of sections on the elements of moral philosophy and on engineering society codes of ethics. Often numerous ethical case studies are considered to demonstrate application of the moral theories and to show how codes of professional ethics can be applied to ethical problems. Typical moral theories considered are the Utilitarianism theory advocated by Bentham and John Stuart Mill and the Respect for Person theory advocated by Kant. Such theories have their limitations. Because of these limitations, application of these theories to ethical case studies can give different results. Engineering students often have a difficult time understanding the limitations of moral theories and interpreting the application of these theories to ethical problems. The approach presented in this short paper helps alleviate these student difficulties.

The mathematical training of engineering students uniquely prepares them for understanding the limitations of ethical moral theories. Engineering students easily grasp concepts from optimization theory. Moral philosophy can be viewed as an optimization problem. When so formulated, the limitations of a number of moral theories is then easily grasped by students. A brief discussion of concepts from optimization theory is first presented. Then, the moral theories of Utilitarianism and Respect for Persons are briefly detailed and formulated using concepts from optimization theory. The advantages of this formulation are then discussed in the Conclusion.

2. Optimization Theory
The ethical decision making process can be formulated as an optimization problem. With this formulation, there is a function, such as utility, which is to be maximized. The function can be expressed in terms of some variable x or a number of variables $x_i$, $i=1,...,n$. There may be, however, conditions imposed on the problem so that some values of $x_i$ may not be allowed. This formulation is the classical formulation of optimization theory where one wants to

$$\text{Maximize } f(\{x\}) \text{ subject to the constraints}$$

$$g_i(\{x\}) \leq 0, \quad i=1,...,n$$

where $\{x\}$ is the set of design variables.
It is instructive to consider a simple optimization problem of two variables subject to several constraints. We want to climb as high as we can up a mountain. Figure 1 shows a contour map of the mountain we wish to climb.

![Contour plot of the objective function, elevation, showing constraints](image)

Figure 1. Contour plot of the objective function, elevation, showing constraints

The objective function of this problem is the elevation obtained or height climbed. As we climb, our position is defined by coordinates on the contour map of Figure 1. Thus, position coordinates are the design variables. Without any constraints on the problem, we would climb to the top of the mountain at location A in Figure 1 at an elevation of 525 feet. Let us assume, however, that the top of the mountain is private property which has been fenced off and that we are not allowed to cross the fences. The fence locations are shown in Figure 1 as cross-hatched lines. Here, the problem is constrained in that we must remain on the down hill side of any fence we encounter. With these constraints, we can only climb to location B in Figure 1 at an elevation of 400 feet.

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In discussing ethical theories, it is useful to use terminology from optimization theory. Definitions of terms are given in Table 1 along with references to the simple mountain climbing example.

Table 1. Terminology from optimization theory

<table>
<thead>
<tr>
<th>Terminology</th>
<th>Definition</th>
<th>Mountain climbing example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design variables</td>
<td>The variables that define the objective functions and constraint equations, {x}.</td>
<td>The position coordinates on the contour map of Figure 1.</td>
</tr>
<tr>
<td>Design space</td>
<td>The space defined by all the possible combinations of the design variables, {x}.</td>
<td>All the region covered by the contour map.</td>
</tr>
<tr>
<td>Feasible design space or feasible solution</td>
<td>All values of {x} which satisfy the constraint equations, (g_i({x}) \leq 0, i=1,..n.)</td>
<td>The area on the down hill side of the fences.</td>
</tr>
<tr>
<td>Objective function</td>
<td>The function to be optimized.</td>
<td>The height climbed.</td>
</tr>
<tr>
<td>Unconstrained optimization problem</td>
<td>Find the optimum value of function (f({x})) with no constraints.</td>
<td>Climb to the top of the mountain as there are no fences to stop you.</td>
</tr>
<tr>
<td>Constrained optimization problem</td>
<td>Find the optimum value of function (f({x})) subject to the constraints, (g_i({x}) \leq 0, i=1,..n)</td>
<td>Climb as high as possible but stay on the downhill side of the fences.</td>
</tr>
<tr>
<td>Optimum feasible design</td>
<td>The design {x} which optimizes (f({x})) while satisfying the constraints, (g_i({x}) \leq 0, i=1,..n.)</td>
<td>Location B.</td>
</tr>
</tbody>
</table>

3. The Ethical Dilemma
To help explain Kant’s theory of Respect for Persons and Mill’s theory of Utilitarianism, these theories will be used to arrive at a solution to an ethical dilemma. The following engineering ethical dilemma will be considered:
Ethical dilemma: Company (A) manufactures product (B). Water is used in the manufacturing process. The manufacturing process introduces a pollutant (C) into the water. The wastewater can be dumped straight into the river or treated to lower the level of the pollutant. The cost of treatment depends upon how much pollutant is removed. A few poor citizens (D) live along the river and depend on fish (F) from the river for food. If the concentration of the pollutant in the water is above a certain level (E), fish in the river will cause sickness of citizens (D). The cost of reducing the concentration of the pollutant (C) below level (E) would negatively effect the profits of Company (A). In fact, if the company does undertake to lower the level of pollutants below (E), the profitability of the plant will be lowered so much that it will have to close, affecting the lives of company employees and shareholders (G). The president of the company (H) is faced with the ethical dilemma: Should the concentration of the pollutant in the discharge water be lowered below level (E).

4. Moral Theories
Moral theories attempt to define terms and link together in a logical way ethical concepts and ethical situations. A number of philosophers such as Kant and Mill have developed moral theories that are important to engineering ethics in that their theories have as their basis moral thinking rather than religion. The ideas of these philosophers has had such a profound influence on engineering ethical thinking and the development of engineering codes of ethics that their moral theories are widely studied in courses on engineering ethics. A brief discussion of the theories of Kant and Mill are next presented.

4.1 Kant’s Theory of Respect for Persons
Kant maintains that ethical actions must adhere to a respect for the individual. Quoting Kant, “All persons ought in all cases to treat human beings as ends in themselves and never as a means only”. Kant is maintaining that it is our moral duty to respect the rights of individual persons. In the ethical dilemma of Section 3, Kant would maintain that one must morally reduce the pollutant level below E out of respect for citizens (D) who live downstream from the plant so that no one becomes sick. Utility is defined as “that which is conducive to the happiness and well-being of the greatest number of people”. Kant is not concerned with maximizing utility. For him, “people can not be killed, deceived, denied their freedom, or otherwise violated simply to bring about a greater total amount of utility”. In Kant’s terminology, one can not limit people’s moral agency.

There are several difficulties with the Respect for Persons theory.
• Kant is concerned only with the effect of actions on individuals, not with other effects such as the effects of actions on the environment. Thus, he would not be concerned if fish were killed by the pollutant if humans were in no way affected.
• Sometimes all solutions seem to limit someone’s moral agency. In the example of Section 3, not reducing the pollutant affects the moral agency of citizens (D) but doing so
affects the moral agency of company employees and shareholders (G).

• Sometimes it seems justifiable to limit moral agency. In our example, most of us would probably feel that the right thing to do is to reduce the level of pollutants even though doing so would affect the moral agency of the company’s employees and shareholders.

• If there are a number of solutions which do not violate anyone’s moral agency, Kant gives no guidelines for choosing one of these solutions over another.

Kant’s basic approach and the limitations of Kant’s theory to our example are obvious when Kant’s theory is formulated as an optimization problem. The problem has no objective function. There are only the constraint equations that individual rights are not violated. With Kant’s theory, one is only looking for a feasible solution not an optimal feasible solution. Kant’s theory is also simplistic in that he only considers constraints involving individual rights. Other constraints such as constraints involving environmental concerns are not considered. His formulation is also poorly posed as his constraint equations involve step functions. With Kant, there is either violation of rights or non violation of rights. The ethical problem is better posed if degrees of violation are considered in the constraint equations.

4.2 Mill’s Theory of Utilitarianism

Utilitarianism, first proposed by David Hume, was developed by Jeremy Bentham. Later it was refined and championed by John Stuart Mill. Mills book entitled Utilitarianism “became the classic statement of Utilitarian philosophy as it developed after Bentham and, as such, has exerted a major influence on ethics, politics, and jurisprudence.” Utilitarianism or the Principal of Utility theorizes that actions should be chosen so as to give the greatest overall utility (happiness) to everyone involved. Quoting Bentham, “By the Principle of Utility is meant that principle which approves or disapproves of every action whatsoever, according to the tendency which it appears to have to augment or diminish the happiness of the party whose interest is in question; or what is the same thing in other words, to promote or to oppose that happiness.” In applying the theory of Utilitarianism to the ethical dilemma of Section 3, for each alternative, the utility of each entity involved would be estimated and these utilities summed to give the total utility.

Let the utility of the ith entity be $u_i$. Then the total utility, $U$, is

$$U = \sum_{i=1}^{m} u_i$$

(3)

where $m$ is the number of entities involved in the ethical situation. The alternative which would maximize the total utility would then be considered to be the correct alternative.
There are a number of problems with the theory of *Utilitarianism*:

- Obtaining a value for the total utility is easier said than done. For example, sometimes it is difficult to decide on what are the entities involved in an ethical situation. Consider the example of Section 3. There are a number of entities affected by the situation. There are the citizens who live downstream from the polluting plant who become ill, the company employees and shareholders, and the company president. The company employees, shareholders, and president receive funds from the company which they spend on goods and services. If the company closes, the employees and shareholders will not be able to spend as much money on goods and services, and thus the goods and service providers will be affected. The providers in turn affect others, etc. The problem is further complicated if the environment is considered. The early advocates of *Utilitarianism* were only concerned with the well being of humans. However, it now seems logical to consider the well being of all living things. Thus, all fish and other aquatic animals should be considered as well as all wildlife feeding on these animals. One can see that just formulating an adequate list of participants is a difficult situation.

- Likewise, estimating for each alternative the utility of each participant is very difficult. Often utility is measured in terms of dollars. If we do this, how much happiness or utility does the president of the company have from the profits he makes from the polluting activities of the company? Is it equal to his salary? How much happiness is lost by a citizen D who becomes sick? Surely it must include his medical expenses but how much is the dollar value for his discomfort? How much loss of utility do we assign to a fishing bird that becomes sick from eating polluted fish? The difficulty of estimating the total utility should be apparent.

- Sometimes *Utilitarianism* seems to perpetuate injustice on a few for the advantage of many. In our example, if only a few people live downstream and eat fish and if we assign a low utility to the wildlife affected, the maximum total utility will occur if the plant keeps polluting. This conclusion is probably not in line with most of the readers’ intuitive feelings.

*Utilitarianism* formulates ethical situations as an unconstrained optimization problem. There are no constraint equations. The violation of the rights of the citizens downstream from the plant could be avoided by having constraints on the problem which prevent loss of individual rights. The mere fact that it is difficult to decide on what participants to consider does not invalidate the theory. When making approximations, one must always choose what terms to consider. Of course, the predicted total utility depends on our assumptions of utilities for each entity involved and our assumptions on individual utilities could be widely in error. Our difficulties in estimating utilities, however, does not invalidate the theory. As with many optimization problems, we must do a sensitivity analysis. If the theory yields the same ethical solution for a wide range of assumptions, we can have confidence in the theory’s ethical solution. If the theory yields different solutions for reasonable changes in our assumptions, then we can conclude that the problem is so sensitive to our assumptions that the theory is unable to yield a reliable ethical solution.
5. Conclusion
This paper formulates ethical problems as constrained optimization problems where one is to find the optimum value of some function such as total utility but with the restrictions that certain constraints, such as individual rights or environmental requirements, are not violated. This unified theory allows one to see the limitations of some of the classical ethical theories. Kant formulates ethical problems as feasible solution problems. He only attempts to find solutions to ethical problems which do not violate individual rights. His theory is simplistic in that it has no objective function and only considers constraints on human rights. The Utilitarians, on the other hand, formulate ethical problems as unconstrained optimization problems. They attempt to maximize total utility or happiness. Their theory is also simplistic in that no constraints are put on ethical problems. Thus, solutions can be obtained which may violate individual rights. Some object to the theory of *Utilitarianism* because the calculation of total utility is so dependent upon values assumed for individual utilities. This sensitivity to assumptions does not invalidate the theory but does point out the need for a sensitivity analysis to determine the affect of assumptions on an ethical conclusion.

The 19th century philosophers such as Kant and Mill can not be faulted too much. The mathematical level of general knowledge at that time was not as great as it is now. Their formulations were simplistic but they had a significant impact of ethical thought. Fortunately, the mathematical level of even engineering freshmen is at a level where they can appreciate the unifying formulation of this paper and insights that this formulation gives of classical ethical theories.

**Bibliographic Information**

Biographical Information

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