HeaTreat

AN INFORMATION TOOL FOR THE METALS INDUSTRY

IPRO 304-A FALL 2007

Table of Contents

0.1 Introduction

PRO 304-A is the continuation of IPRO 330 (Spring 2006) and was created to develop an Information Tool for the Metals Industry with a focus on Heat Treatment, in this case. The development of an Information Tool for Heat Treatment requires across-disciplinary knowledge of the fundamentals of heat treatment process, as well as an in-depth understanding of and the practical skills required for the development of computer software.

a. Team Roster

The IPRO 304-A Team is composed of seven individuals representing six fields of study (majors).

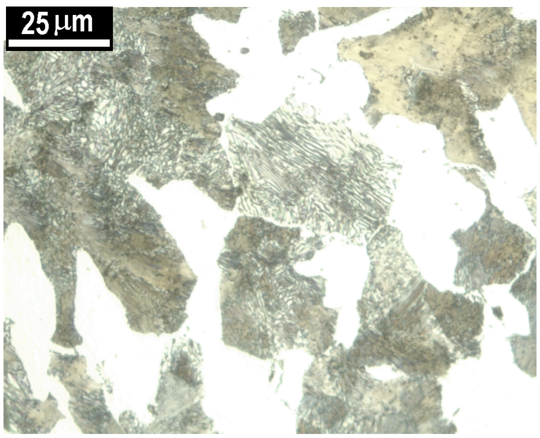
(in alphabetical order)

- Vlad Antal, *Senior - Mechanical Engineering*
- Steven Banaska, *Senior - Electrical Engineering*
- Hussain Biyawerwala, *Junior - Electrical and Computer Engineering / Math*
- John Groszko, *Senior - Computer Science*
- Ryan Jay, *Senior - Mechanical Engineering*
- Kyle Koning, Senior - *Materials Science and Engineering / Mechanical Engineering*
- Sangwook Lee, Senior - *Electrical Engineering*

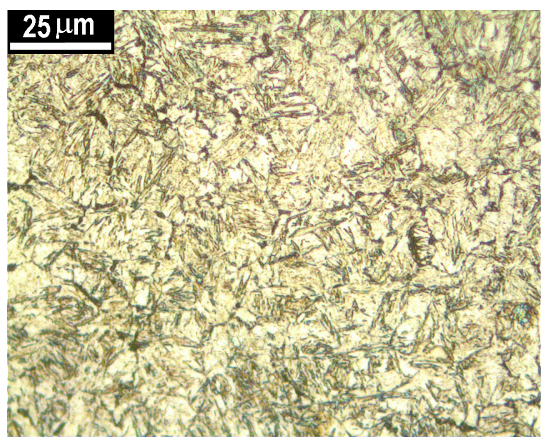
0.2 Background

a. Heat Treatment of Steel

Steel is the most common engineering metal used in modern society and industry. It is an iron based alloy with a wide variety of properties based on chemical composition and processing. The most common alloying addition is carbon, due to its ability to strengthen and harden steel through heat treatment. While there are many different types of heat treatment, those that which are of most concern for this project are quenching and tempering. At temperatures of approximately 750 °C carbon atoms and iron atoms form a



solid state solution: carbon dissolves in solid iron to make steel. Depending on the rate at and manner in which the iron/carbon solution is cooled, different types of steel are formed. The process of rapidly cooling steel is known as quenching. Slow, controlled quenches can produce a form of steel called pearlite, seen at left, that is strong, hard, and tough. Fast quenches produce a type of steel known as martensite, seen at right, that is very strong, extremely hard, extremely brittle, and, in most cases, useless for engineering applications. Both images are of the same piece of steel and at the same magnification, but heat treated differently.



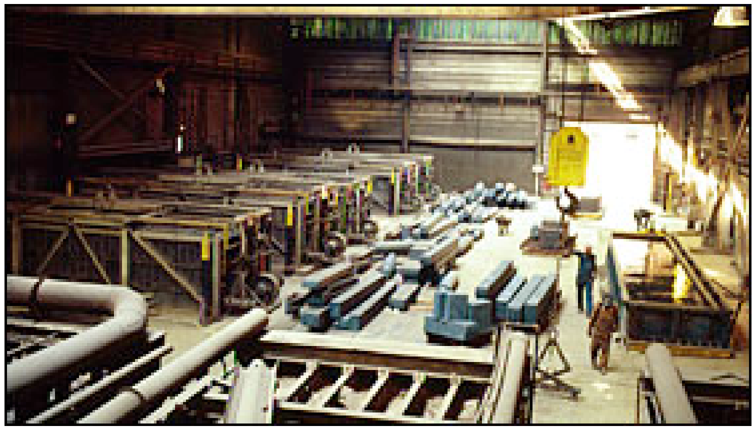
In order to reduce the hardness and brittleness of quenched steel to a point that the steel is useable, it must be tempered. To temper steel it must be heated to a temperature (determined by the alloying content of the steel and the desired properties after tempering) and held at that temperature for a set period of time (also determined by alloying content and the desired properties after tempering). As with quenching, different temperatures and different times produce different properties. A steel that is tempered at a higher temperature for a longer time will become softer and tougher compared to a steel temperature at a lower temperature for a shorter time. Tempering time also is influenced by the dimensions of the part to be tempered. A larger part has a larger thermal heat capacity and takes longer to reach a uniform temperature needed for a more uniform temper. Irregularities in part shape or size can result in irregularities in the heat treatment and must therefore be considered in the design of the heat treatment system.

The quench/temper process is generally conducted a single "batch" at a time. While some automated systems do exist, especially for other forms of heat treatment, many quench/temper steps of manufacturing involve the loading of one furnace with a finite number of parts, treating, and then cooling. Production speed, therefore is dependent on the number of parts able to be loaded into one furnace at one time.

b. **A. Finkl & Sons Company**

A. Finkl & Sons Company Steel (entrance seen below), located in Chicago, IL is the world's leading producer of forging die steels, plastic mold steels, die

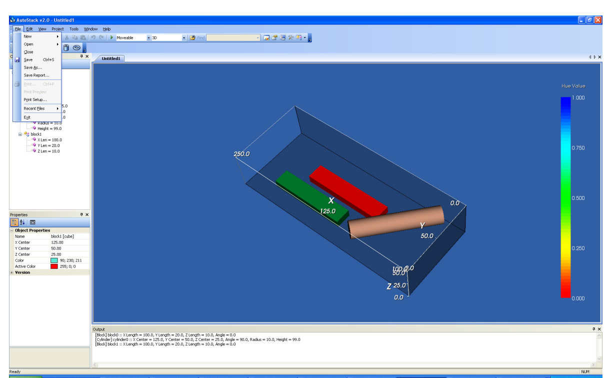
casting steels and custom open-die forgings. Examples of Finkl customers are mostly manufacturers building tooling for their operations or manufacturers using Finkl parts within a finished product. Finkl has a long and successful history of producing the highest quality specialized steel in the industry. Therefore, it is no surprise that Finkl has some of the highest standards and specifications for their products in the world. There high standards have led to a rejection of nearly 7% or approximately 14,000,000lbs of their manufactured parts. For quenching/tempering processes, this simply means starting the process over; re-quenching and re-tempering instead of scrapping the part. At Finkl, when a part fails to meet the specification as a result of an improper heat treatment, it is often because of the irregular size and shape of the piece of steel. Finkl's parts range in size from around 500lbs to around 100,000lbs and usually take one of over one hundred different general shapes. Of these one hundred plus shapes, however, there exist a nearly infinite number of dimensional differences. Finkl also offers dozens of types of steel. The typical manufacturer buying from Finkl steel usually utilizes the Finkl-made part in a highly customized and low-volume application such as a long-life die for making automotive body panels or crankshafts for behemoth mining equipment. In summary, there is not a consistent size, shape, or material being mass produced by Finkl. Their operation sees a dynamic number and type of part. Nearly all of these parts share a common bond though -- they need to be heat treated.



Since heat treatment parameters are influenced by size, shape, and type of steel, there exist limited combinations of parts that can be heat treated simultaneously within a single large furnace. A heat treatment area at Finkl can be seen at right. The furnaces are positioned in the left side of the photograph and the pieces to be heat treated (in this case quenched) are in stacked directly in front of them. Each furnace consists of a hearth and a bell. The bell makes up the walls and ceiling of the furnace and can be removed with a crane hoist to expose the hearth on the shop floor. A crane can then be used to move the steel parts into the furnace. The size and shape of the parts, as well as that of the furnace limits what parts can be loaded. The current method employed by Finkl is make a drawing of the loading setup based on engineer experience and trial & error: Finkl engineers take a visual inventory of what parts are available for heat treat from their work-order database and create the layout. This methodology slows production and is inefficient.

c. **IPRO 330 Spring 2006**

A previous IPRO team was assembled to develop a software solution to Finkl's problem. IPRO 330 worked during the Spring 2006 semester to develop a program to digitally represent the parts to be heat treated and their respective positions within a furnace model. Their program, known as AutoStack (shown at right) was able to represent actual parts in a 3D environment where part manipulation was pos-



sible. A user could then translate and rotate parts in order to achieve a fit within the furnace. This program made it possible to replace the "hand-drawn" method but had some disadvantages that limit its use. The AutoStack program was developed using an obscure developmental software package that was not easily upgradeable and was incompatible with the work order database in place at Finkl. Perhaps most important was the program's lack of solid modeling. For most computer-based analysis of parts, solid modeling is required in order to accurately represent the entire part at all times. These shortcomings made AutoStack difficult to use and an impractical base from which to build an robust and capable program.

0.3 Purpose

The issue at hand is the development of an information tool for A. Finkl & Sons, similar to the solution developed by IPRO 330 Spring 2006, capable of optimizing the heat treatment process by maximizing part quality and batch size. The subsequent saving in scrap/rework as well as increased productivity would save Finkl a substantial amount of time and money. In order for a solution to be fully functional for a long period of time it is necessary to develop a program consisting with industry-standard compatibility using industry-standard components. Additionally, to make the tool easier to use for Finkl, a database of their own parts must be modeled in a format that can be easily modified and utilized by the solution.

a. **Project Goals**

In summary, the IPRO 304-A Team set a long-term (multiple IPRO Team/semester) goal of developing a software solution capable of optimizing the heat treatment process at A. Finkl & Sons.

The software must be capable of the following:

- Maximizing batch size
- Outputting the best loading pattern based on:
  - ➡ Available parts (in heat treat area)
  - ➡ Work order priority
- Functioning with Finkl's work order database
- Utilizing files output by popular CAD packages such as ProEngineer or UGS
- Accepting upgrades developed by future IPROs that could include:
  - ➡ Migration to a handheld device for engineers and managers
  - ➡ Thermodynamic modeling functionality
- Building a complete database of all known Finkl part shapes

Owing to time constraint of a single semester, the IPRO 304-A Team developed two short-term or semester goals to work towards that would result in a substantial step towards the completion of the complex goal described above.

b. **Semester Goals**

Goal 1.

Reconstruct the AutoStack software to eliminate the existing drawbacks and program limitations while at the same time building a highly capable and compatible platform.

Goal 2.

Construct a part template portfolio of the Finkl shapes compatible with the existing Finkl word order database and modeled in an industry standard CAD program.

c. **Original Project Plan**

In order to effectively accomplish the two semester goals, the team scheduled an initial meeting with Finkl to better understand the issue. Due to unforeseen schedule difficulties, the Team was not able to gather a complete set of information and desired features at that time. Based on what was able to gleaned from the meeting, the Team developed a work plan to outline the software development process and parts modeling process, as seen below. The plan included seeking advice on industrial software from Dr. Zhiyong Hu of the Mechanical, Materials, and Aerospace Engineering Department at IIT, meeting with Finkl a second time, and a large amount of work on still unfamiliar topic.

- Build Dependencies - Sep 27
  - ➡ Project Tracking Software
  - ➡ Get all developers set up
- Requirements Specification - Oct 11
  - ➡ Meet w/ Finkl
  - ➡ Research Loading Algorithms
- Basic Functionality - Oct 25
  - ➡ Multiple Document Interface
  - ➡ Open/Save Files
  - ➡ View Functionality (Translate, Rotate, etc)
  - ➡ Place Parts in Furnace
- Team Building- Nov 15
  - ➡ Develop Team Logo
  - ➡ Develop Team Slogan
  - ➡ Design T-Shirts

•Feature Complete - Nov 15
   •Implement Loading Algorithms
   •Auto Part Placement

- Usability Testing - Nov 22
  - ➡ Design Test Cases
  - ➡ Testing / Bug Reporting

- Bug Fix Complete - Nov 27
  - ➡ Fix Bugs
  - ➡ Begin 2nd iteration

- Parts Modeling - Nov 22
  - ➡ Obtain Parts Spec
  - ➡ Model Parts

d. **Original Work Assignments**

The following division of labor was developed to complete the above work plan.

Developers
John Groszko

IPRO Goals
Kyle Koning
Ryan Jay

Finkl Relations
John Groszko
Kyle Koning

Modeling
Ryan Jay
Vlad Antal

Usability
Hussain Biyawerwala
Steven Benaska
Sangwook Lee

However, it became apparent after beginning work, gaining more information from Finkl, and receiving advice from Dr.Hu that our project plan and team assignments needed to be reevaluated and reconstructed so as to better accomplish our goals. This matter will be further discussed in section **0.5 Assignments**.

0.4 Research Methodology

To build an information tool of the desired type it was necessary to review the work of IPRO 330 in more detail. Once the Team was familiar with the past, Dr. Hu was consulted for advice on industrial software development tools. Dr. Hu was gracious enough to make a presentation to the Team with a short-list of suggestions. Each suggestion was investigated and evaluated. Similarly, a list of popular CAD packages was investigated to choose which platform to use.

Criteria for choosing software included:

- Capabilities (solid modeling, thermodynamic functions, etc)0
- Compatibility (with CAD programs and Finkl's system)
- Availability and Access (based on cost and licensing)
- Development potential (robustness of development tool packages)
- How update the development tools are kept

Several meetings with Finkl steel were organized and input was sought from the Finkl staff, including the Chief Metallurgist and Plant Manager. The Team presented our then-current view of the project and our steps for completion. The representatives of Finkl were then given the opportunity to provide the Team with suggestions, comments, and concerns about the project.

After gathering information, described above, the Team was able to modify the project plan and proceed accordingly. More detailed information on this topic is discussed below in section **0.5 Assignments**.

0.5 Assignments

a. Modified Project Plan

Based on the information gathered, the Team decided create a build environment to develop a program that would utilize two very powerful developmental tool kits. Many modern pieces of software not created "from scratch." Programs are created from code packages and developmental tools kits assembled together in a build environment. The Team chose HOOPS 3D Application Framework to serve as the graphical output for the program. 3D ACIS Modeler was chosen to provide 3D modeling. Both developmental tools are used in the most powerful CAD and 3D modeling suites commercially sold today.

A second version of the project plan was created around our gathered information and software tools, as seen below.

- Build Dependencies - Sep 27
  - ➡ Meet w/ Dr. Hu
  - ➡ Project Tracking Software (Trac)
  - ➡ Central Source Code Repository (Subversion)
  - ➡ Get all developers set up

- Requirements Specification - Oct 11
  - ➡ Meet w/ Finkl
  - ➡ Research developmental packages

- Basic Functionality - Nov 8
  - ➡ Multiple Document Interface
  - ➡ Open/Save Files
  - ➡ View Functionality (Translate, Rotate, etc)
  - ➡ Place Parts in Furnace

- Communication Building- Nov 15
  - ➡ Develop program Logo
  - ➡ Develop communications standards (colors, font, etc)

- Usability Testing - Nov 22
  - ➡ Design Test Cases
  - ➡ Testing / Bug Reporting

- Bug Fix Complete - Nov 27
  - ➡ Fix Bugs
  - ➡ Begin 2nd iteration

- Parts Modeling with ProEngineer- Nov 22
  - ➡ Obtain Parts Spec
  - ➡ Model Parts

b. Modified Work Assignments

In order to best accomplish the project plan, a new division of labor was created. The previous assignment set did not provide enough manpower to create a working program in the alloted time. The new assignment set took into account personal interests, as well as hard technical skills with the hope that increased interest in individual tasks would help motivate and create a deeper personal investment in the project. The following represents the assignments chosen for the modified project plan.

- **Software Development Group -** *Responsible for software creation*
  - ➡ Steven Banaska *Software Developer*
  - ➡ John Groszko *Lead Software Developer*
  - ➡ Sangwook Lee *Software Usability Tester*

- **Template Portfolio Development Group** - *Responsible for modeling all available parts in ProEngineer*
  - ➡ Vlad Antal *3D Modeler*
  - ➡ Ryan Jay *3D Modeler*

- **Communications and Project Support Group** - *Responsible for the design and creation of documents, digital media, and IPRO Deliverables*
  - ➡ Hussain Biyawerwala *Document Coordinator and Secretary*
  - ➡ Kyle Koning *Visual Media and Communications Designer*

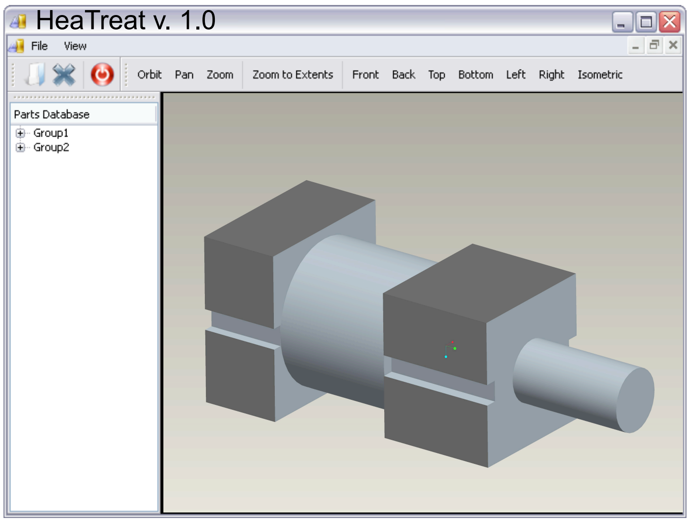
0.6 Obstacles

Only one Team member is a student of Computer Science. Learning the basics of computer science itself is a difficult task, but Software Development Group members were forced to re-introduce themselves to programming and take cues from the Lead Software Developer, John Groszko. Once an understanding of how to build the program was achieved, the task of building a program capable of meeting the requirements proved difficult. However, steady work and consistent effort, along with the help of Dr. Hu, the IT Staff at Finkl, and John Groszko, a program was formed.

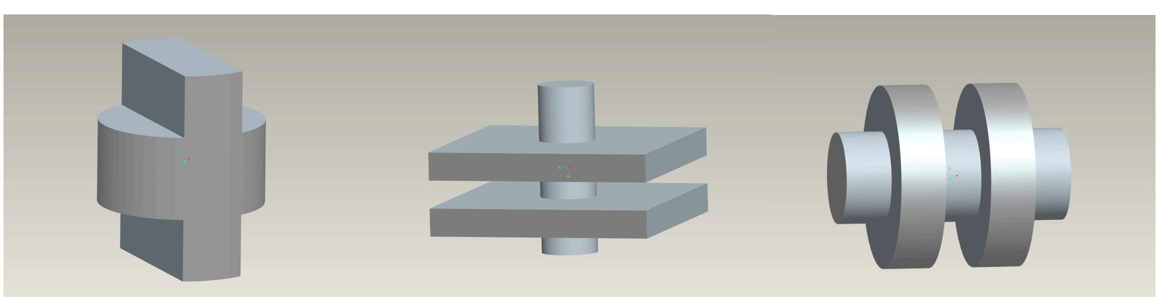
Initially there was difficulty in gathering the input of A. Finkl & Sons due to the fact that they are a very busy company. Eventually, with the assistance of student interns from IIT working at Finkl and IIT alumni at Finkl, meetings were able to be scheduled and input gathered.

0.7 Results

HeaTreat - the software solution created by IPRO 304-A represents the achievement of the first goal of the semester - the delivery of a solution foundation capable of meeting the project goals. The HeaTreat environment, seen at left, utilizes fully solid 3D modeling with a simple, but effective user interface. The use of HOOPS Application Framework and ACIS 3D Modeler make possible the robust graphics and highly compatible backbone of the program -- HeaTreat is fully compatible with ProEngineer files and is capable of opening the files created as part of the template portfolio. Since the HeaTreat environment utilizes fully solid modeling and part files compatible with ProEngineer, thermodynamic modeling of the entire heat treatment furnace is possible and can be added and is currently available through developmental tool kits. The growing trend of increased power of handheld computers suggests a complete migration to a handheld device is nearly within reach. *The HeaTreat logo can be see on the cover of this report.*



The template portfolio of actual Finkl parts has also part files produced. Additional examples are shown below.



0.8 Recommendations

a. Future IPRO

Future IPRO teams have a variety of options available should this IPRO be continued. The robust solution developed by IPRO 304-A has made possible the ability to construct and add all the functions necessary to achieve the project goals described previously. To review, it our solution will accept functionality that will permit:

- Thermodynamic modeling for best part placement within the furnace
- Loading based on desired heat treatment, available parts, and maximum batch size

Additionally possibilities exist for future teams to complete a comprehensive shape database (as opposed to the current template database) and migrate a fully finished solution to a handheld device for engineers and foreman.

a. Team Reflections

It was clear to all members of the Team that the software development process does not start "from scratch." The Team was able to utilize available components available in development packages to great success. However, since the Team members were not computer programming savvy, a substantial learning curve existed. Future IPROs working on this project MUST have at least four Computer Science majors. The current Team achieved success through hard work and was fortunate that the development did not require substantial programming skills. Future additions to the HeaTreat program will require the greater expertise of Computer Science majors.

0.9 References

www.spatial.com

0.10 Acknowedgements

•**A. Finkl & Sons - Project Sponsor**

- ➡ Sean McCann (Project Engineer) - Primary Liaison at Finkl
- ➡ Guy Brada (Chief Metallurgist) and the Metallurgy Staff
- ➡ The IT Staff

•Dr. Zhiyong Hu (IIT MMAE Dept.) - Assistance and Guidance with setup of the software build environment

•Spatial Corp. - Educational Licensing for ACIS and HOOPS

•IPRO 330 (Spring 2006) - Taking the first steps towards a fully functional solution.

0.11 Code of Ethics

Overarching Principle: "Help A. Finkl & Sons increase productivity and quality control by developing a software tool for heat treatment maximization and part tracking."

1) Law
Canon: The IPRO team will work to ensure that all software copyrights and applicable patents are respected and uphold under all local, state, and federal laws.

Pressure: Complete the project quickly or within a preset deadline.
Risk: Copy software code in an unlawful manner or without proper consent of the software developer/owner.
Risk: Unlawfully deconstructing existing software and copying their methods of operation.

2) Contracts
Canon: The IPRO team will abide by the terms of agreement with software and software development package providers.

Pressure: Use the software for commercial purposes.
Risk: Violate the terms of contract by granting access to the software to parties outside of the development team.
Risk: Permitting sale/delivery of software and it's components to any parties prior to the establishment of commercial licensing.

3) Professional Codes
Canon: The Association for Computing Machinery has established guidelines and codes of conduct for those computing engineering and the team is expected to follow these guidelines. (The ACM code of ethics may be found at: http://www.acm.org/about/code-of-ethics)

Pressure: Produce a stable program, delivered within a time period of one semester.
Risk: Not produce a program that "will avoid harmful effects to health and welfare" by producing a product that has not been thoroughly tested for system stability and maintainability.
Risk: Produce a program with taking steps to "**Acquire and maintain professional competence**," thereby ensuring that all those developing the software or capable of creating a safe and dependable program.

4) Industry Standards

Canon: The IPRO team will work within the existing computer platform (MS Windows) utilized by A. Finkl and Sons and conform to the technology guidelines of their Informational Technology Department.

> *Pressure*: Find simpler/faster computer platform
> *Risk*: Develop software for a computer platform not approved by A. Finkl and Sons.
> *Risk*: Develop software requiring substantial upgrades to the equipment possessed by A. Finkl & Sons.

5) Community
Canon: The standards of conduct set forth by Illinois Institute of Technology will be strictly observed by all members of the IPRO team. (The Illinois Institute of Technology code of conduct can be found at the following internet address: http://www.iit.edu/~osa/Handbook/FinePrint.html.)

> *Pressure*: Complete the project by the delivery date, IPRO Day.
> *Risk*: Misrepresent the work of another party as the product of the sole efforts of the team members.
> *Risk*: Take/copy, without permission and official approval, the work of another IPRO team.

6) Personal Relationships
Canon: IPRO team members will develop and preserve honest and respectful communications/interactions with teammates, advisors, and project stakeholders.

> *Pressure*: Make yourself/your work stand out and appear to be of high quality.
> *Risk*: Produce a poor quality finished product and conceal it from team/advisors.
> *Risk:* Negatively condemn the accomplishments of a teammate to make your own accomplishments seem to be of higher merit.

7) Personal/Moral Values
Canon: No requirements will be set forth by the IPRO team that will require team members to order or participate in actions/events that will breach the personal values (personal, moral, spiritual, etc) of a team member or stakeholder.

> *Pressure*: Require meetings for project work every Sunday.
> *Risk*: Stress/violate the religious beliefs of Christian team members who observe Sunday as the Sabbath.
> *Risk*: Require team members/advisors to cancel previously made plans with their friends/families for additional project work.