A HUMAN FACTORS META MODEL FOR U.S. NUCLEAR POWER PLANT CONTROL ROOM MODERNIZATION

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ABSTRACT

Over the last several years, the United States (U.S.) Department of Energy (DOE) has sponsored human factors research and development (R&D) and human factors engineering (HFE) activities through its Light Water Reactor Sustainability (LWRS) program to modernize the main control rooms (MCR) of commercial nuclear power plants (NPP). Idaho National Laboratory (INL), in partnership with numerous commercial nuclear utilities, has conducted some of this R&D to enable the life extension of NPPs (i.e., provide the technical basis for the long-term reliability, productivity, safety, and security of U.S. NPPs). From these activities performed to date, a human factors meta model for U.S. NPP control room modernization can now be formulated. This paper discusses this emergent HFE meta model for NPP control room modernization, with the goal of providing an integrated high-level roadmap and guidance on how to perform human factors R&D and HFE for those in the U.S. nuclear industry engaged in the process of upgrading their MCRs.

Keywords: Experience with Control Room Modernization, Light Water Reactor Sustainability, Human Factors, Human Factors Engineering, Instrumentation & Control Systems

1 INTRODUCTION

Affordable electricity generation is an essential component to powering a nation's robust and globally competitive economy. Nuclear power plants (NPP) account for approximately 19% of current base load electricity generation in the United States (U.S.). Other technologies that reduce reliance on foreign produced fossil fuels and provide base load electricity cost-competitively at a national scale are still under development. Thus, without suitable replacements for nuclear power, the generating capability of nuclear energy in the U.S. must be maintained through the continued safe and efficient operation of the current fleet of NPPs.

The U.S. Department of Energy's (DOE) Light Water Reactor Sustainability (LWRS) research and development (R&D) program provides the technical foundations for licensing and managing the long-term, safe, and economical operation of NPPs. LWRS focuses on R&D that contributes to the national policy objectives of energy security and economic sustainability. One area in the LWRS program is the Advanced Instrumentation, Information, and Control Systems (II&C) Technologies pathway, which includes human factors R&D and human factors engineering (HFE) to enable main control room (MCR) modernization, because the instrumentation and control (I&C) technologies in operating NPP MCRs are a potential life-limiting factor.

For the last several years, DOE researchers, including human factors researchers and HFE professionals at Idaho National Laboratory (INL), have collaborated with numerous commercial NPP utilities on control room modernization. From these activities, a meta model for U.S. NPP control room modernization can now be formulated that synthesizes the lessons learned that have been gained. This paper describes the meta model for control room modernization with the goal to provide insights on performing human factors R&D and HFE to others in the U.S. nuclear industry who are considering upgrading their main control rooms.

2 COMPONENTS TO THE HUMAN FACTORS META MODEL

Just as a meta analysis is a statistical analysis that combines the results of multiple scientific studies, a meta model is the combination of multiple models into a bigger model, with the premise that the meta model provides new and important insights that are not apparent from the individual components. This human factors meta model is comprised of three components called: 1) the Scientific Method, 2) the Engineering Method, and 3) the Business Perspective. Each one of these components is described below.

2.1 The Scientific Method

The Scientific Method, as adopted from [1], is a high-level model of the approach scientists use to conduct R&D that provides the technical basis for the solutions that are implemented for NPP control room modernization. As seen in Figure 1, the basic steps of the Scientific Method are to: 1) ask a question, 2) do background research, 3) construct a hypothesis, 4) test the hypothesis with an experiment, 5) verify that the procedure is working, 6) analyze the data, 7) determine whether the results align with the hypothesis or not, and 8) communicate the results. Another feature to note in the Scientific Method are the feedback loops, one that is initiated when the procedure is not working, and one operative for the new empirical insights obtained from the experiment. That is, past experimental results become the basis for new research and follow on experiments.

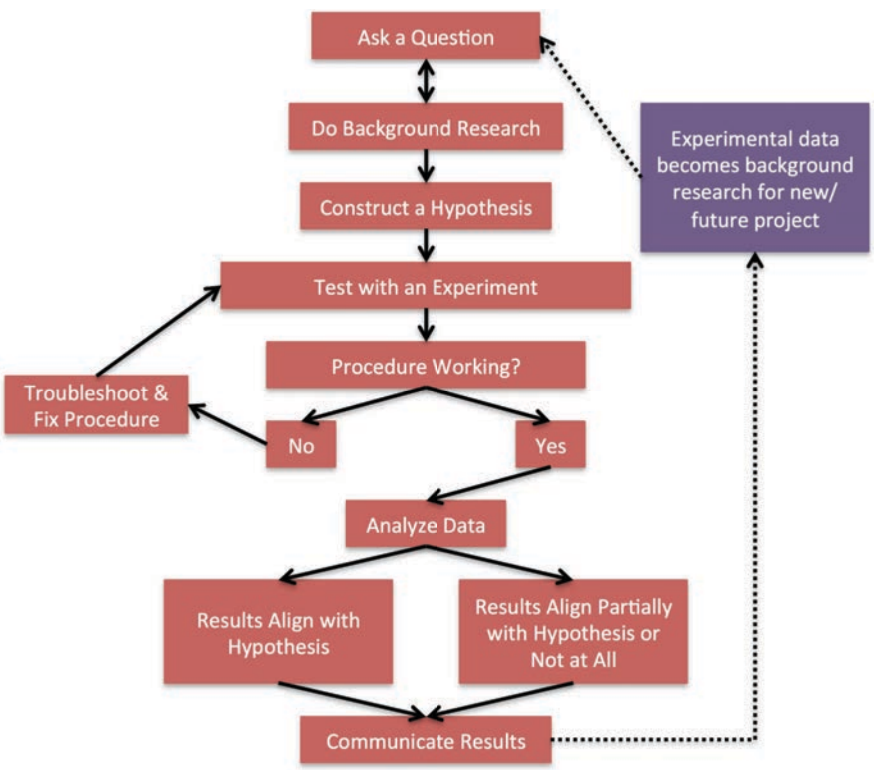

Figure 1. The Scientific Method.

2.1.1 The Scientific Method as Implemented

The Scientific Method has been implemented for control room modernization in a variety of ways over the years as INL and the nuclear industry have collaborated on this work. Researchers in this area have employed variations of the Scientific Method that are derived from their disciplines of specific expertise, which in this case includes human factors, cognitive psychology, usability, ergonomics, and social psychology. Examples of this include R&D on task-based overview displays in the MCR [2], the identification of requirements for MCR computer-based procedures [3], and the development of operator performance metrics for early design evaluation in control room modernization activities [4]. Additional examples of LWRS sponsored work that has been performed on the topic of control room modernization and other topics under the Advanced II&C Technologies pathway can be found at [5].

2.2 The Engineering Method

The Engineering Method, also adopted from [1], is a high-level model of the approach engineers take to solve the problem of modernizing NPP control rooms. As seen in Figure 2, the basic steps of the Engineering Method are to: 1) define the problem, 2) do background research, 3) specify requirements, 4) brainstorm, evaluate and choose a solution, 5) develop and prototype the solution, 6) test the solution, 7) determine whether the solution meets the requirements previously specified or not, and 8) communicate the results. It is important to note that in doing background research and specifying requirements for NPP control room modernization, the engineer must consider regulatory requirements, applicable standards, and other industry guidance, which often means taking a systems engineering approach. The iterative nature of the Engineering Method is also important, whereby the engineer makes design changes, develops new prototype solutions, retests and evaluates those solutions if the previous solution only partially met or did not meet the requirements, and continues to cycle through this process until the solution meets the requirements.

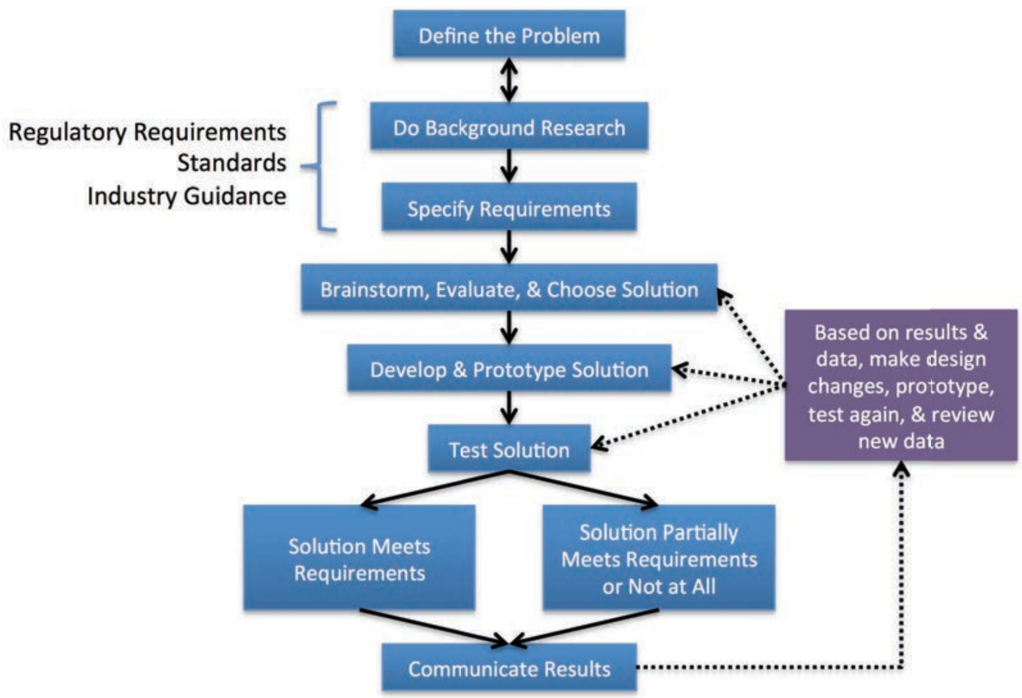

Figure 2. The Engineering Method.

One additional and important feature to highlight about the Engineering Method is its underlying philosophy, and how that philosophy is very different from the philosophy of the Scientific Method. Specifically, Beder [6] describes engineering as an art, not a science, which relies upon human judgment. This means that in the Engineering Method, “Heuristics are used in the absence of better knowledge or as a short-cut method of working out something that would be too expensive or time consuming to work out more scientifically” (pg. 39).

2.2.1 The Engineering Method as Implemented

For the human factors and HFE aspects of control room modernization in the commercial nuclear industry, the Engineering Method is implemented in at least two specific ways. The first implementation is through [7], which is the U.S. Nuclear Regulatory Commission's *Human Factors Engineering Program Review Model*. The four phases of their HFE program review model, and the specific sub-elements, as seen in Figure 3, correspond to the steps of the Engineering Method. For example, Planning and Analysis corresponds to 1) define the problem, 2) do background research, and 3) specify requirements. Design corresponds to 4) brainstorm, evaluate and choose a solution, and 5) develop and prototype the solution. Verification and Validation corresponds to 6) test the solution and 7) determine whether the solution meets the requirements previously specified or not.

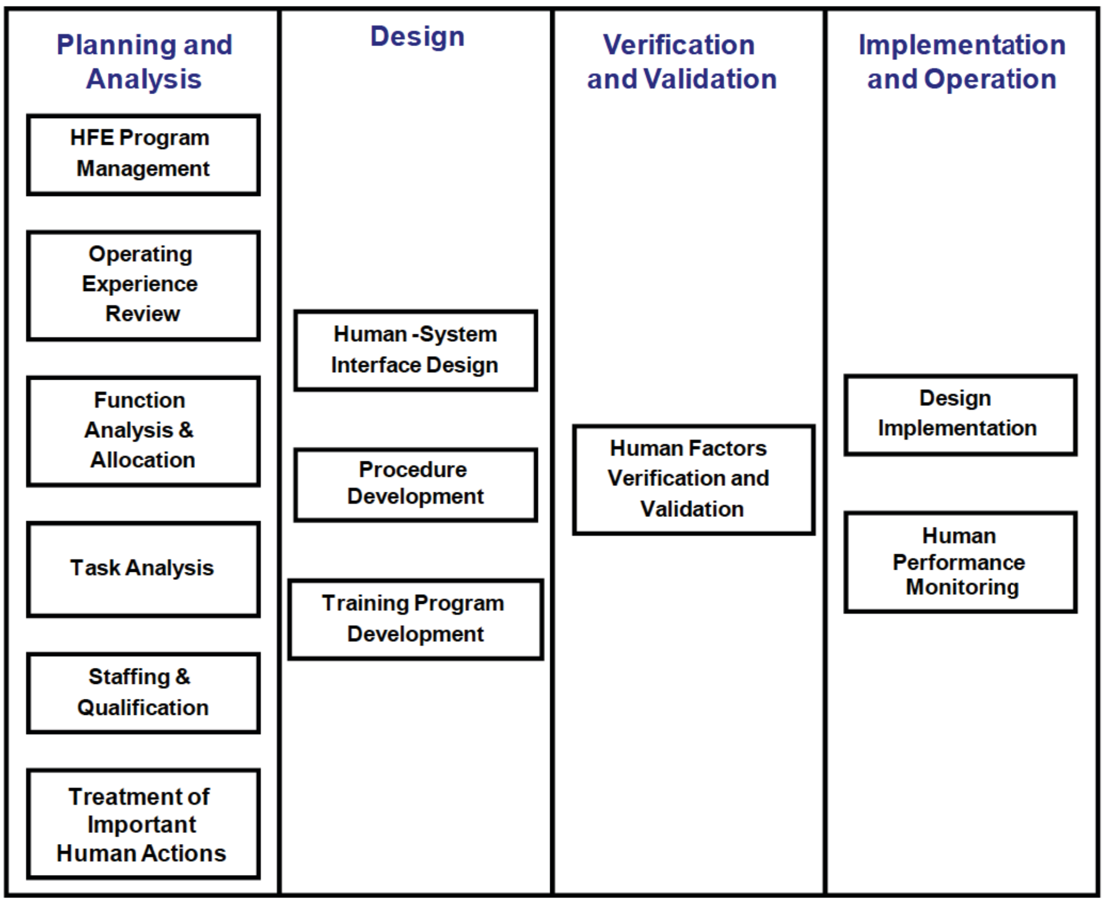

Figure 3. HFE Phases Covered in NUREG-0711, Rev. 3.

The second implementation of the Engineering Method is through [8], which is the 2005 publicly available version of Electric Power Research Institute's (EPRI) *Human Factors Guidance for Control Room and Digital Human-System Interface Design and Modification: Guidelines for Planning, Specification, Design, Licensing, Implementation, Training, Operation, and Maintenance*. EPRI has since published a revision of this guidance. As seen in Figure 4, there is a similar correspondence between EPRI's conceptualization of the overall engineering and I&C design process and the Engineering Method.

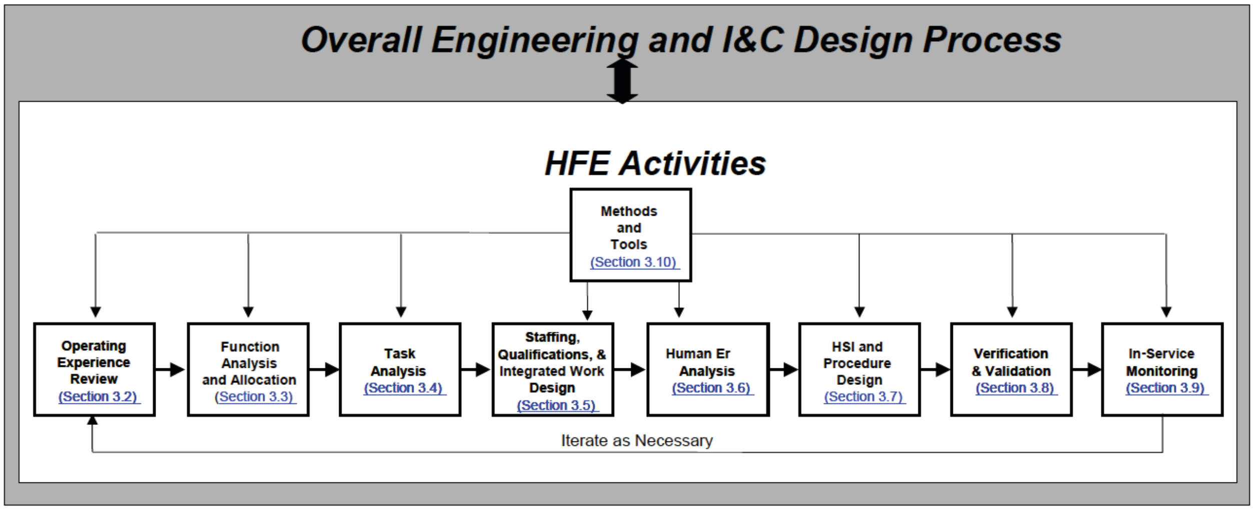

Figure 4. EPRI Model of HFE Activities (Adopted from [8] Figure 3-1).

2.3 The Business Perspective

The Business Perspective is a high-level representation of the economic factors that must be considered in the context of NPP control room modernization. Commercial U.S. NPPs must consider the financial aspects of control room modernization because they have to compete economically with other forms of electrical generation (e.g., fossil fuels and renewable energy). As such, the costs of NPP control room modernization are always evaluated from a Business Perspective. As seen in Figure 5, NPP control room modernization activities need to consider: 1) initial costs, 2) the products that are developed to modernize MCRs, 3) the benefits of those products, 4) the stakeholders 5) how those stakeholders would perceive the benefits afforded by those products, 6) the degree to which that would affect their willingness to pay, and 7) the ultimate return on investment.

Figure 5. The Business Perspective.

2.3.1 The Business Perspective as Implemented

As previously noted by Joe, Thomas, and Boring [9], in translating this generic Business Perspective and applying it to the specific context of NPP control room modernization R&D, it becomes the following questions:

- What can operators do with this new technology that they could not do before? That is, by investing in these products, what are the expected human factors technical improvements?
- What would be the improvements in terms of operations performance outcomes?
- How would this show up in business or key performance indicators (KPIs)?

Figure 6 provides a number of examples of how these questions would be answered when performing human factors R&D and HFE for NPP control room modernization. Human factors researchers, HFE professionals, and utilities need to keep this aspect of MCR modernization in mind as they perform or consider performing their research, because if the business case cannot be made for the work they are doing or want to do, it will almost assuredly not be funded to proceed.

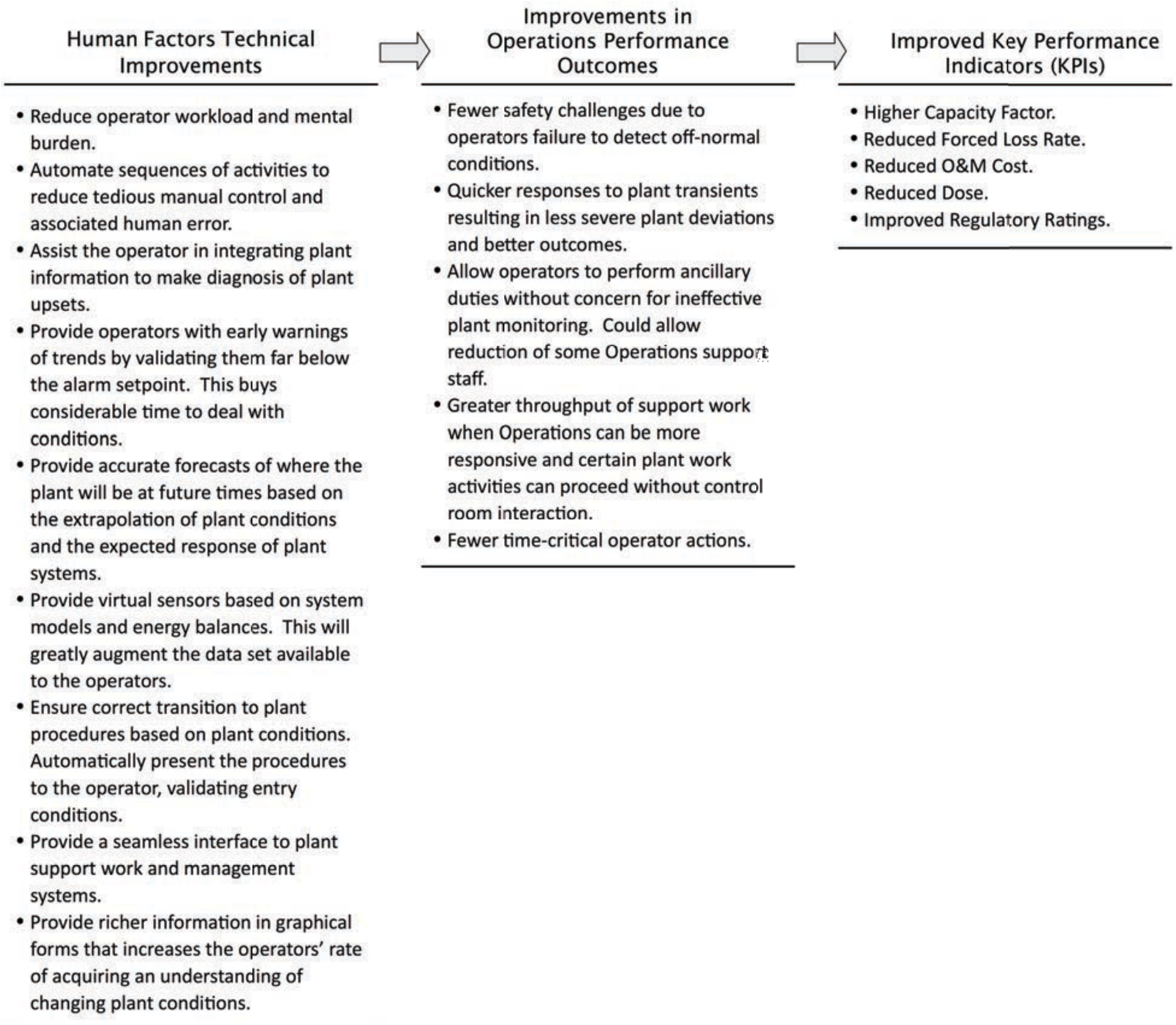

Figure 6. The Business Perspective as Implemented for NPP Control Room Modernization

Additional in-depth business case analyses have been performed under the LWRS Advance II&C pathway for various control room modernization research activities [10, 11, 12], and are also available at [5].

3 A CRITICAL REVIEW OF THE META MODEL COMPONENTS

There are a number of clear differences between the Scientific Method, Engineering Method, and the Business Perspective. Each of these components of the human factors meta model have their strengths and weaknesses, and a corresponding group of people who are a) critical of and b) defenders of that component. Table I below highlights a few of the strengths and weaknesses of each component (e.g., the Scientific Method, Engineering Method, and Business Perspective) as seen from the perspectives of the critics of that component (✖), and the defenders of that component (✔).

Table I. Some Pros and Cons of Each Component from the Perspectives of the Critic ✖ and Defender ✔

Scientific	Engineering	Business
✖ Slower	✔ Faster	✔ Focuses on Efficient Use of Scarce Resources
✖ More Expensive	✔ Less Expensive	✔ Impartial to the Use of the Scientific or Engineering Method (Utility Focused)
✔ Establishes Empirical Truth	✖ Relies on Consensus and Judgment for Decisions	✖ Its Focus on Efficiency is at Odds with Quality

As it is with most things, however, the truth of each component is less black and white than the critic or defender would argue they are. In reality, each component is more grey than black and white. For example, the Scientific Method should establish the empirical truth, but has on occasion overstated the confidence with which the truth is known. Similarly, the Engineering Method should be faster and less expensive than using the Scientific Method, but experience to date in modernizing NPP control rooms might cast some doubt on those assertions. Inherent in this faster and cheaper issue is the fact that human judgment, or heuristics are used in determining the "factor of safety" [6] in the design of engineered systems, and even though informed professional opinion is used as a basis, people can nevertheless disagree with what "factor of safety" is safe enough. Finally, with the Business Perspective, scarce resources can sometimes be used inefficiently when decisions are influenced by personal preferences or inherent conflicts of interest (e.g., nepotism), and the fact that quality can be compromised for the sake of efficiency (e.g., Deepwater Horizon) is an ever-present concern. A more realistic assessment of the relative strengths and weaknesses of each meta model component is presented in Table II.

Table II. A More Realistic Assessment of Each Component

Scientific	Engineering	Business
Slower (presumably)	Faster (ideally)	Focuses on Efficient Use of Scarce Resources (ideally)
More Expensive (presumably)	Less Expensive (ideally)	Impartial to the Use of the Scientific or Engineering Method (ideally Utility Focused)
Establishes Empirical Truth (ideally)	Relies on Consensus and Judgment for some proportion of decisions (usually)	Its focus on Efficiency can be at odds with Quality (usually)

4 A HUMAN FACTORS META MODEL

Given the criticisms levied against the Scientific Method, Engineering Method, and Business Perspective in the Section above, it becomes clear that no single component of the meta model is sufficiently robust to address all of the complexities and demands of NPP control room modernization. Instead, all three components are needed. Thus, the human factors meta model for NPP control room modernization is a high-level combination of the three components. As seen in Figure 7, the meta model is composed of the Engineering Method, the Scientific Method, and the Business Perspective and is meant to show how the strengths and weaknesses of each component need to be combined and balanced. The fact that all three circles in this figure are the same size is because none of the components is more valuable or has greater significance over the others. Also, note that in this meta model, there are areas where the components overlap or share common ground, and there are parts where they are separate and maintain their uniqueness from the other components. This is by design, and is meant to convey that each component of the meta model is a specific specialization and brings a unique contribution of expertise to the problem of NPP control room modernization. Furthermore, based on the years of collaborative R&D and HFE that INL has performed with numerous commercial NPP utility owners, it is my observation that 1) it is important for the whole team of engineers and scientist to understand the particular control room modernization problem that is being solved, and what specific human factors and HFE problems are present (i.e., context matters), and 2) it is important to consider every team member's particular areas of expertise and their familiarity with a given discipline (i.e., area of expertise matters), because both of these factors have a significant effect on which aspects of the problem are emphasized and studied, and which aspects are not.

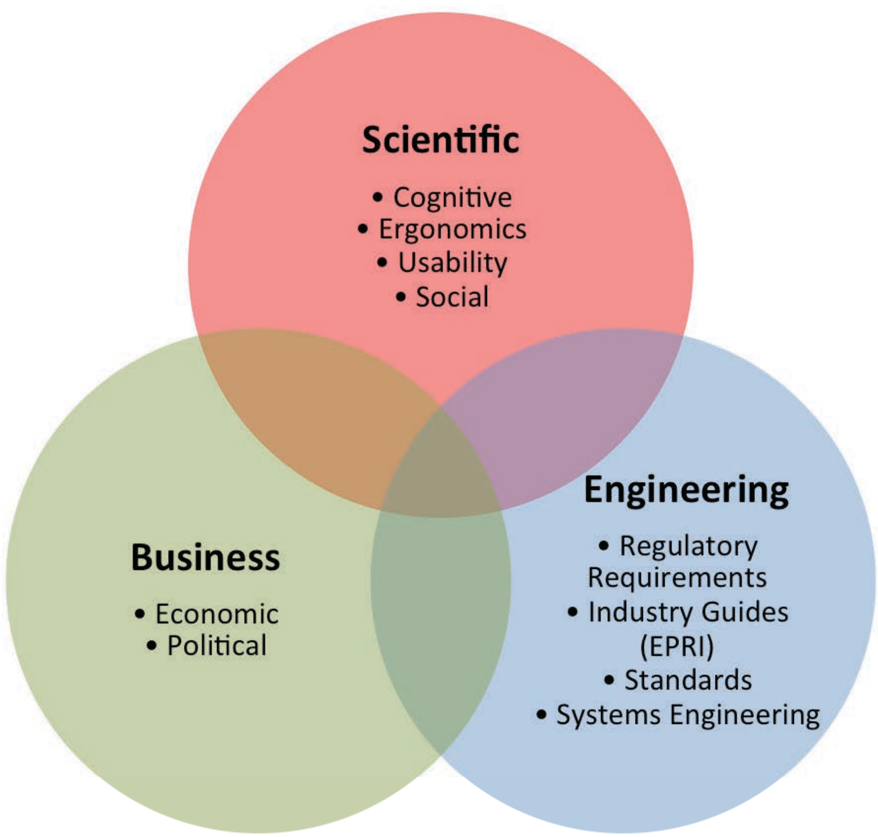

Figure 7. A Human Factors Meta Model for NPP Control Room Modernization

5 CONCLUSION

NPP control room modernization is a challenging problem that requires the efficient coordination of multi-disciplinary expertise. The success of MCR modernization can be enhanced with greater integration of different disciplines and perspectives. Based on my years of experience as a researcher working on NPP control room modernization, I believe that MCR modernization is most successful when the team of collaborators works in the area of 3-fold overlap of the meta model (Figure 7), as this is the space where there is balance among the three components, and the perspectives and expertise of all team members is used in solving the problem.

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