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**IMPROVING BUSINESS PERFORMANCE THROUGH THE
INTEGRATION OF HUMAN FACTORS ENGINEERING INTO ORGANIZATIONS
USING A SYSTEMS ENGINEERING APPROACH**

by

MONICA F. PHILIPPART
B.S. Mechanical Engineering, Florida Institute of Technology, 1997
M.S. Industrial Engineering and Management Systems, University of Central Florida, 1999

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Major Professors: Waldemar Karwowski
Linda Malone

ABSTRACT

Most organizations today understand the valuable contribution employees as people (rather than simply bodies) provide to their overall performance. Although efforts are made to make the most of the human in organizations, there is still much room for improvement. Focus in the reduction of employee injuries such as cumulative trauma disorders rose in the 80's. Attempts at increasing performance by addressing employee satisfaction through various methods have also been ongoing for several years now. Knowledge Management is one of the most recent attempts at controlling and making the best use of employees' knowledge. All of these efforts and more towards that same goal of making the most of people's performance at work are encompassed within the domain of the Human Factors Engineering/Ergonomics field. HFE/E provides still untapped potential for organizational performance as the human and its optimal performance are the reason for this discipline's being. Although Human Factors programs have been generated and implemented, there is still the need for a method to help organizations fully integrate this discipline into the enterprise as a whole. The purpose of this research is to develop a method to help organizations integrate HFE/E into it business processes.

This research begun with a review of the ways in which the HFE/E discipline is currently used by organizations. The need and desire to integrate HFE/E into organizations was identified, and a method to accomplish this integration was conceptualized. This method consisted on the generation of two domain-specific ontologies (a Human Factors Engineering/Ergonomics ontology, and a Business ontology), and mapping the two creating a concept map that can be used to integrate HFE/E into businesses. The HFE/E ontology was built by generating two concept maps that were merged and then joined with a HFE/E discipline taxonomy. A total of

four concept maps, two ontologies and a taxonomy were created, all of which are contributions

to the HFE/E, and the business- and management-related fields.

I dedicate this work to my family. To my parents, Leopoldo and Helen, and to my husband Geoffroy, whose continued encouragement and support have been so important during this effort. Also to my children, Biancamaría and Alejandro, who had to learn at an early age to be understanding of their mom's time. I hope to have been and continue to be a good role model, and prove that it is possible to keep a good balance in life.

I also dedicate this dissertation to those who have given me that special moral support I have needed throughout my quest for improvement.

ACKNOWLEDGMENTS

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CHAPTER ONE: INTRODUCTION

1.1 Problem Definition

Most industries today realize that Human Factors Engineering/Ergonomics (HFE/E) is an important contributor towards system performance. It is widely recognized that the human is a major (some say the most important) component of any system and that, as such, the performance of the human has great repercussions on the overall performance of a system. Jeffrey Pfeffer, Professor of Organizational Behavior at Stanford University, studied the sources of successful organizations in the US. He believes that "Success comes from delivering value to your customers, and the ability to deliver value comes from having sound conceptions of what customers want and value, *and how to organize and manage people to produce that value* [my emphasis]" (Pfeffer, 1998, p. 13). Technology and organizational structure may be imitated, whereas the qualifications and motivation of a workforce are difficult to imitate. Knowledge and skills (particularly cognitive skills) are a key organizational asset or competitive advantage (Duffy and Salvendy, 1999). One of the most recent attempts at making the most of these valuable assets is through Knowledge Management. But Knowledge Management tools and techniques are not able to include tacit knowledge since it only exists in the heads of the workforce. HFE/E can at least partially address tacit knowledge by encouraging and increasing the likelihood that people use their knowledge to their greatest abilities.

Although the HFE/E discipline can be used for countless purposes, the most common applications are legal (Zink, 2005) and/or product-enhancement motivated. Hence, HFE/E is most often found in safety and health departments with the objective of reducing employee

injuries and illnesses, and/or in engineering or technical departments where HFE/E principles are applied to hardware or software with the purpose of achieving that competitive advantage that "user friendly" products provide. But the goals of HFE/E are much more ambitious than that. HFE/E strives to achieve complete system safety, productivity and satisfaction. By defining a system as an entire organization, it is apparent that limiting the use of the HFE/E technology to individual projects deprives organizations from the possible benefits of applying this discipline throughout the enterprise.

But for HFE/E to be adequately addressed, it must be managed as integrated within the whole business rather than as something added as an afterthought or separate project. People are central to all organizational activities, making companies sociotechnical systems. People interact with other people. People perform tasks. People use equipment and software. People interact with the work environment. People reside within and interact with the rest of the organization. These people interactions encompass the domain of HFE/E and, for this reason, the HFE/E contribution must be integrated throughout the whole organization in order to fully contribute to better overall business performance.

This project was conceived as a result of observations made at 6 different large organizations which lead to the conclusion that companies need a tool to help them incorporate HFE/E into the way they operate their business. Therefore, this study proposes a method to integrate the HFE/E discipline into businesses to enhance their overall performance.

1.2 Research Opportunities

The literature reviews below will show the connections among HFE/E, Sociotechnical Systems, Macroergonomics, Knowledge Management and Human-Systems Integration (HSI); how these concepts relate to the performance of organizations; and how HFE/E specifically is typically applied in organizations. The benefits of considering the human as a critical part of a system and integrating HFE/E into system design have been strongly documented. This benefit is clearly widely accepted. Great effort has been expended in the generation of programs that aim at system performance optimization through the integration of, among other disciplines, HFE/E in organizations. In addition, current research is focusing on the development and improvement of knowledge management tools, which seem to be under high industry demand.

But the literature review also identified a gap addressing how HFE/E can contribute to the improvement of business performance. HFE/E can aid HSI and Knowledge Management to improve business performance. Macroergonomics applies ergonomics principles to the design of work systems and how organizations are structured; but micro-ergonomics must take over from there and ensure that HFE/E principles are applied within and throughout the organization's processes. As indicated in the introduction, only some of the HFE/E specialty areas are commonly applied in industry; mostly those that can address issues affecting worker compensation claims and consumer product desirability. But there are many other opportunities for HFE/E to enhance business performance which are not clearly shown in the literature. Multiple studies were found about ergonomics used in a corporate setting to fix a problem (mostly Cumulative Trauma Disorders or other safety issues), corroborating the idea for this project. There are also multiple documents detailing how to apply HFE/E principles to the

design of a piece of equipment (MIL-STD1472 is just one example). Programs such as MANPRINT describe the HFE/E activities required for the integration of human considerations into system acquisition processes (concept development, test and evaluation, documentation, design, development). However, the focus of these is on systems within the system that is the organization, but not the organization itself.

An organization may be defined as "the planned coordination of two or more people who, functioning on a relatively continuous basis and through division of labor and hierarchy of authority, seek to achieve a common goal or set of goals" (Robbins, 1983, p.5). If an entire organization is considered a [work] system, then Robbins' definition of an organization would be the definition of that system. This concept of a system, with its division of labor and hierarchy of authority, implies structure. Macroergonomics would, therefore, apply HFE/E principles to determine the structure of that system (the organization). But for a complete Human-Systems Integration from the HFE/E domain perspective, micro-ergonomics has much to contribute. Defining the work system as an entire organization, the application of the HSI philosophy would provide the benefit of optimal overall organization performance.

There is not one document that organizations can go to for recommendations on which of the myriad of HFE/E specialties should be applied to which of the multiple business processes to achieve the HFE/E part of a comprehensive HSI to improve overall business performance. There is no methodology or structure available to help organizations integrate HFE/E into business processes; thus, the goal of this project is to propose a method that organizations can use to integrate HFE/E throughout their businesses and, therefore, expand the HFE/E currently relatively small contribution from individual processes or projects to the overall enterprise.

1.3 Research Goal and Objectives

The goal of this research project was to propose a practical method that organizations can use to integrate the HFE/E discipline into business processes. This integration will help companies benefit from applying HFE/E not only in traditional areas such safety and engineering, but also in the management and organization of the business itself, helping achieve Human-Systems Integration throughout the enterprise. Integrating HFE/E into a business will also help improve the management of knowledge throughout the enterprise.

This research intended to answer the following questions:

- At what level should business activities be evaluated for HFE/E integration?

- How can a company use the HFE/E discipline to affect overall business performance?

- Where can a company incorporate HFE/E to improve its overall performance?

- What HFE/E study areas can be of value to business processes?

The objectives that this project aimed to achieve to meet the goal of this research effort and answer the questions listed above included:

1. To identify and describe the basic business processes characteristic of a generic organization.

2. To categorize and characterize HFE/E specialty areas to make the integration of the HFE/E discipline into business processes practical.

3. To determine where each HFE/E specialty area should be incorporated into businesses to benefit overall performance.

1.4 Research Scope

The outcome of this project is applicable to any type of business. All functioning organizations must accomplish basic business activities regardless of structure. This work was founded on those basic functions, no matter what the product or service of the business is, and regardless of how the reporting relationships are structured in the organization.

This project will help organizations determine where different HFE/E specialty areas could be incorporated into the business to thoroughly integrate HFE/E knowledge throughout the enterprise. The outcome of this effort may be used in full or in part at the discretion of the users based on the needs, budget, or any other criteria organizations may have. In other words, even if this project's recommendations are used only in part (i.e., if not all suggested HFE/E specialty areas are incorporated into the business), organizations can still benefit from the application of HFE/E and improve their business performance.

CHAPTER TWO: REVIEW OF LITERATURE

2.1 Human Factors Engineering/Ergonomics

The definition of ergonomics has evolved over the years to reflect advances of the discipline. In 1991, Licht and colleagues identified 130 definitions of human factors and ergonomics. The following definition was inspired by Chapanis and Helander (Karwowski, 2005):

Ergonomics and human factors use knowledge of human abilities and limitations to the design of systems, organizations, jobs, machines, tools, and consumer products for safe, efficient, comfortable and satisfying human use.

In 2000, the International Ergonomics Association (IEA) Council made the following their official ergonomics definition:

Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.

In most European countries, the driving factors for ergonomics have been worker safety, health, and comfort (Karwowski, 2005). In the U.S., HFE/E emerged as a discipline after World War II. The new, sophisticated war equipment brought with it many design problems which caused human errors. Allegedly, more U.S. pilots died during training than in war activities. For this reason, much of the research in HFE/E in the U.S. has been sponsored by the Department of Defense and, as a consequence, the HFE/E information available is therefore heavily influenced

by results from military research. Other U.S. federal agencies have sponsored research on many civilian applications including the Federal Highway Administration, the National Aeronautics and Space Administrations, and the Federal Aviation Agency. In 1980, after evaluating the impact that organizational trends would have in the HFE/E profession for the Human Factors Society Select Committee on the Future of Human Factors, W. A. Hendrick concluded that ergonomics would need to integrate organizational design and management factors into its research and practice. Part of what lead to this conclusion was the clear indication that increasing world competition was going to require more efficient work system structures and processes in order for companies to be competitive. Today, ergonomics in industry has the dual purpose of promoting productivity and improved work conditions. Several recent studies have shown significant improvements in productivity as a result of these ergonomics measures (Karwowski, 2005).

HFE/E has three domains of specialization representing deeper competencies in specific human attributes or characteristics of human interaction. The IEA describes these domains as follows:

1. Physical ergonomics, concerned with human anatomical, anthropometric, physiological and biomechanical characteristics as they relate to physical activity.

2. Cognitive ergonomics, concerned with mental processes, such as perception, memory, reasoning, and motor response, as they affect interactions among humans and other elements of a system.

3. Organizational ergonomics, concerned with the optimization of sociotechnical systems, including their organizational structures, policies, and processes.

In addition, Hendrick indicated in his 2001 presentation to the Human Factors & Ergonomics Society Potomac Chapter that ergonomics has at least five identifiable major components, which he called technologies:

1. Human-machine interface technology or hardware ergonomics, primarily concerning the study of human physical and perceptual characteristics and the application of these data to the design of controls, displays, seating, workstations and related workspace arrangements.

2. Human-environment interface technology or environmental ergonomics, concerning the effect of various physical environmental factors, such as illumination, heat, cold, noise and vibration on human performance, and the application of these data to the design of physical environment for people.

3. Human-job interface technology or work design ergonomics, concerning the design of jobs to ensure proper workload and characteristics such as task variety or having different meaningful things to do in one's work, identity of sense of job wholeness, significance or perceived job meaningfulness, autonomy or control over one's work, and feedback or knowledge of results.

4. Human-software interface technology, the central focus of cognitive ergonomics, concerning the way people think, conceptualize, and process information, and the application of these data to software design.

5. Human-organization interface technology or macroergonomics, concerning the interfacing of employees with the over-all organizational design of the work system so as to most effectively utilize both the personnel and technology employed in the system in responding to the organization's external environment.

Ergonomists contribute to the design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of people. There are ample opportunities for the HFE/E discipline to fulfill its potential contribution to organizational performance because, currently, the most common applications are legal and product-enhancement motivated. Many studies have focused on addressing the rise in worker compensation claims related to injuries caused by awkward postures, repetitive or prolonged activities, forceful exertions, vibration, unfavorable environmental factors, etc. This rise in compensation claims and the light brought on the related HFE/E issues made very popular just a small portion of the vast possible applications of the HFE/E discipline. Only part of what HFE/E can contribute has been largely applied in industrial settings, mostly with the aim of reducing effort and improving quality and occupational safety (Parker, 1995).

2.2 Sociotechnical Systems

Emory and Trist (1960) coined the term "sociotechnical system" to convey the nature of complex human-machine-environment systems. The sociotechnical system concept views organizations as open systems whose purpose is to transform inputs into desired outputs. Organizations are considered open because they are affected by and depend on the environment in which they exist for their survival. To achieve this transformation, organizations use two major components: technology in the form of a technical subsystem, and people in the form of a personnel subsystem. The two subsystems interact with one another and are therefore

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interdependent, giving rise to the important concepts of joint causation and joint optimization. This means that optimizing either the technical or the personnel subsystems and then fitting the other to the first would result in sub-optimization of the joint work system. The decomposition of sociotechnical systems in the mentioned subcomponents clearly shows the relationship between sociotechnical systems and HFE/E. All sociotechnical systems should use HFE/E principles for optimal performance, since people are a major subsystem. The sociotechnical system concept also illustrates that people should not be addressed separately, but in conjunction with the rest of the system for optimal system performance.

2.3 Macroergonomics

Macroergonomics applies ergonomics principles to the design of work systems and how organizations are structured. Using this discipline, an organization's structure is determined in terms of ideal complexity, formalization and centralization – the three major components of an organization's structure – based on the organization's jobs, types of people in the organization and their combined needs while considering the technology, the people and the environment in/with which both interact (Hendrick, 2001). Another term for macroergonomics is organizational ergonomics, which was described above, according to the IEA, as being concerned with the optimization of sociotechnical systems, including their organizational structures, policies, and processes.

Macroergonomics was mentioned earlier as one of the three domains of HFE/E and one of the five HFE/E technologies. It is addressed separately here to emphasize that this HFE/E competency acknowledges that, since organizations are sociotechnical systems, HFE/E principles need to be applied to how their work systems are designed. The design of a work system's structure (which includes how it is to be managed) involves consideration of the key elements of three major sociotechnical system components: a) the technological subsystem, b) the personnel subsystem, and c) the relevant external environments. Each of these three major sociotechnical system components has been studied in relation to its effect on the fourth component − organizational structure. Empirical models have been developed to optimize a system's organizational design. The macroergonomics perspective, however, needs to be carried through to the micro-ergonomic considerations of the work systems to achieve a complete integration of HFE/E in the organization. Micro-ergonomic issues must be taken into consideration in the tasks and in the human-machine, human-environment, and human-software interfaces, for the levels of productivity, safety and health, and quality of work life to be greater than the simple sum of the parts (Hendrick, 2001).

2.4 Human Systems Integration

Although technology is constantly improving, the number of catastrophic incidents can be expected to rise because the opportunities for both human and machine failures increase with complexity, and rapidly developing technologies involve greater and greater operational complexity (Perrow, 1999). The cost of failure, rework, and waste resulting form substandard manufacturing has been estimated at over $600 billion a year. Through human error in design and operation or repair of machines, people are hurt, killed, made unhappy or, in the best case, inconvenienced, and people are both the cause and the solution to this problem. The quality of any service or product produced by any organization depends ultimately on several factors, all under the control of people. It is a fundamental belief of Booher (2003) that through a focus on the human element it is possible to achieve both a) dramatic reductions in waste and victims and b) dramatic increases in system performance and productivity; but the human element must be considered a critical component of the system. People, technology and organizations make up the three top-level components of any complex system (Sage and Rouse, 1999, p.57). This recognition of the importance of the human element is generally accepted by systems engineering and systems management philosophies. The belief that dramatic organizational benefits are most likely to be achieved through focusing on people is the Human Systems Integration philosophy, which aids the systems engineering process by bringing into play the various human-centered domains.

The Human Systems Integration (HSI) Working Group of the International Council on Systems Engineering (INCOSE) developed the following definition:

Human systems integration is the interdisciplinary technical and management processes for integrating human considerations within and across all system elements; an essential enabler to systems engineering practice.

The human in HSI includes all personnel who interact with the system in any capacity. These may be system owners, users/customers, operators, maintainers, support personnel, trainers, etc. The primary objective of HSI is to integrate the human as a critical system element whether it participates as an individual or in a group. During system design, the human is treated equally with other system elements such as hardware and software. This promotes a "total system" approach that comprises humans, technology (hardware and software), the operational context, and the necessary interactions between and among the elements to strive for joint optimization. HSI processes facilitate exchanges among the different human-centered domains - which include manpower, personnel, training, HFE/E, environment, safety, occupational health, habitability, and survivability - without replacing each domain's responsibilities (Mueller, 2008).

HSI therefore promotes carrying the macroergonomics efforts through to micro-ergonomic considerations for optimal system performance. Part of this ambition, then, requires a good HFE/E integration into the system.

2.5 Application of HFE/E in Organizations

As discussed earlier, macroergonomics has the potential to improve the ergonomic design of organizations by ensuring that the respective work system's designs harmonize with the organizations' critical sociotechnical characteristics. The macroergonomics approach to

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determining the optimal design of a work system's structure consists on determining things like (Hendrick, 2001):

a) Horizontal differentiation, prescribing how narrowly or broadly jobs must be designed and, often, how they should be departmentalized.

b) Level of formalization and centralization dictating:

    a. The amount of routine versus freedom of choice to be designed into the jobs, human-machine and human-software interfaces

    b. Level of professionalism to be designed into each job

    c. Design requirements for the information, communications and decision support systems

c) Vertical differentiation, imposing many of the design characteristics of the managerial positions including span of control, decision authority and nature of decisions to be made, etc.

But this only accomplishes part of the HFE/E efforts necessary for a complete HSI. Because much of the research in HFE/E in the U.S. has been sponsored by the Department of Defense, much of the HFE/E information available is heavily influenced by results from military research. For example, the U.S. army became the first large organization to fully implement an HSI approach. In 1986, the army decided to change the focus of equipment developers from just the equipment to the "total system", considering soldier performance and equipment reliability together as one single system. The management and technical program, designed to improve weapons systems and unit performance, was called the Manpower and Personnel Integration (MANPRINT). The Department of Defense Directive (DoDD) 5000.1, Enclosure 1, paragraph

E1.1.29, states, "The PM shall apply human systems integration to optimize total system performance (hardware, software, and human), operational effectiveness, and suitability, survivability, safety, and affordability." This approach recognized that every platform, weapon system, computer, radio, piece of equipment, and even every soldier is not only a unique entity, but also is a part of a greater system. But the most unique aspect of the MANPRINT program was effective integration of human factors into the mainstream of system definition, development, and deployment (Mueller, 2008). MANPRINT is divided into seven domains which, although often interrelated in practice (i.e., changes in system design to correct a deficiency in one domain nearly always affect another domain), have their own independent goals and associated responsibilities. The MANPRINT domains are:

1. Manpower, addressing the number of military and civilian personnel required and potentially available to operate, maintain, sustain, and provide training for systems. It is the number of personnel spaces (required or authorized positions) and available people (operating strength).

2. Personnel, addressing the cognitive and physical characteristics and capabilities required to be able to train for, operate, maintain, and sustain materiel and information systems. Personnel capabilities are normally reflected as Knowledge, Skills, Abilities, and Other characteristics (KSAOs).

3. Training, defined as the instruction, education, on-the-job, or self development training required providing all personnel and units with essential job skills, and knowledge required to effectively operate, deploy/employ, maintain and support the system.

4. System Safety, referring to the design features and operating characteristics of a system that serve to minimize the potential for human or machine errors/failures that cause injurious accidents.

5. Health Hazards, addressing the design features and operating characteristics of a system that create significant risks of bodily injury or death.

6. Soldier survivability, addressing the characteristics of a system that can reduce fratricide, detectability, and probability of being attacked, as well as minimize system damage, soldier injury, and cognitive and physical fatigue.

7. Human Factors Engineering.

By separating the seven domains this way, the expectations of HFE/E become clearer, as some of the responsibilities that could be considered as part of HFE/E are clearly removed. The goal of HFE/E remains to maximize the ability of an individual or crew to operate and maintain a system at required levels by eliminating design-induced difficulty and error. Human Factors engineers are expected to work with systems engineers to design and evaluate human-system interfaces to ensure they are compatible with the capabilities and limitations of the potential user population. HFE/E also includes the requirements of the HSI Domain of Habitability including the physical environment and, when appropriate, requirements for personnel services and living conditions that have a direct impact on meeting/sustaining system performance or that have such an adverse impact on quality of life and morale that recruitment/retention is degraded. But it excludes the manpower, personnel, training, system safety, and other requirements that are sometimes taken on by Human Factors engineers just because they have knowledge necessary.

The activities specific to HFE/E in the MANPRINT program include:

- evaluating predecessor systems and operator tasks,

- analyzing user needs,

- analyzing and allocating functions,

  - analyzing tasks and associated workload,

  - evaluating alternative designs through the use of equipment mock-ups and software prototypes,

  - evaluating software by performing usability testing,

  - refining analysis of tasks and workload,

  - using modeling tools such as human figure models to evaluate crew station and workplace design and operator procedures,

  - confirming that the design meets HFE/E specification requirements,

  - measuring operator task performance,

  - and identifying any undesirable design or procedural features.

The Navy also created a Human Engineering Process as part of the SC-21 S&T Manning Affordability Initiative (S&T). The first goal of this effort was to define a generalizable process for human engineering compatible with systems engineering practices. The second goal was to define a process that can be used as a roadmap for identifying or developing (when required) tools and capabilities for the S&T project's Human-Centered Design Environment (HCDE).

The Human Engineering Process is broken into six high-level steps (Figure 1): Mission Analysis, Requirements Analysis, Function Analysis, Function Allocation, Design, and

Verification. Some of these steps are specific to HFE/E, but others are more general and either cross into other disciplines or may be seen as system engineering process steps. Steps in this last category may not even be performed by human engineers or with the intent to "do" human engineering, but their outputs typically include information or other products that drive decisions or are otherwise needed within the human engineering discipline (Booher, 2003).
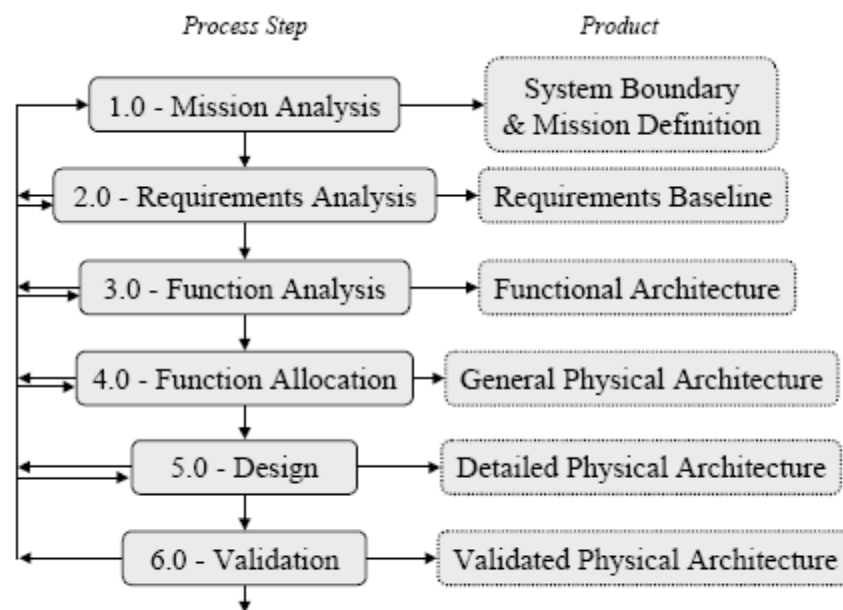
Figure 1: The Navy's human engineering process (U.S. Navy, 1998).

The desired objectives of the MANPRINT approach to systems integration, and the HF domains of the army program have both been adopted by the U.S. Department of Defense with its HSI program, and in the UK Ministry of Defence with its human factors integration (HFI) program. The Federal Aviation Administration (FAA) has also implemented major portions of MANPRINT into its HFI program. Additional HSI programs appear as the HSI philosophy

evolves, but the same concepts and principles apply whether the term used is HSI, HFI or MANRINT (Booher, 2003).

2.6 HFE/E and Business Performance

The concepts described in the previous sections can be applied to business performance. A varied array of literature was reviewed to research the extent to which HFE/E is currently used by businesses. Many titles appeared to address this topic, but upon further review the actual content clearly fell short of the complete possibilities of applications that HFE/E can provide to enhance the performance of businesses. The intent of this part of the literature review was to find information about HFE/E efforts that benefit organizations as a whole rather than focusing on specific projects (e.g. product design) or solving specific problems (e.g. reducing the number of cumulative trauma disorders in the workplace). Just a few examples of the numerous titles that were mistakenly thought to address the desired topic along with very brief summaries showing that they are too focused for this project's intent follow next.

"Adopting an integrated approach to ergonomics implementation" (Attaran, 1996) attempts to demonstrate that implementing ergonomics is essential in curbing the number of *workplace injuries* and discusses guidelines for implementation.

"Making the best ergonomics investment" (Riel & Imbeau, 1995) discusses a comprehensive decision support process that is incorporated into the appropriate *safety management process*.

"The economics of ergonomics: Finding the right fit" (Bencivenga, 1996) discusses the benefits of establishing ergonomics programs to educate workers on proper use of equipment *to prevent injuries*.

"Targeting ergonomics in your business plan" (Schneider, 1995) explores the relationship between office ergonomics and corporate business plans, and provides three steps to develop an effective ergonomics program that is aligned with a company's business goals. The premise of the discussion is that employees are an asset (a premise in this proposed research effort as well); but the focus is on using ergonomics to ensure the *health of the employees* and how that will lead to improved performance.

"Organizing for strategic ergonomics: Implementation of an effective ergonomics system" (Pater & Button, 1992). This study presents strategies on implementing an ergonomics program, but again, the reason given for the need to establish an effective ergonomics system is to prevent employees from contracting *cumulative trauma disorders*; that being the focus of the discussion.

"Implementing an ergonomics program: Developing procedures" (Roughton, 1993) is a tutorial that limits the discussion to how *workplace injuries* in the form of cumulative trauma disorders can be reduced through the development and implementation of corporate ergonomics programs.

"Factors affecting the adequacy of ergonomic efforts on large-scale-system development programs" (Hendrick, 1990) is a study conducted to identify how ergonomic factors are considered in system design and development, and differences among major development programs in both the magnitude and effectiveness of the overall ergonomics effort. In this study, the term "system" refers to something to be designed by design groups (not the organization as a

whole), so the study's results specifically addressed the integration of ergonomics into *engineering design groups* and related tasks.

"Human factors, management and society" (Zink, 2006) discusses the potential of this applied science and the results that can be gained. Several important points are discussed together in this document: the need to optimize human well-being to improve overall system performance, ergonomics being based on a holistic approach, the need for ergonomics to use management language and be included at the top management level, the need to use the same approaches or management systems as are used for total quality management and performance measurement, the need for participatory ergonomics (employee involvement). The paper still leans towards a safety and health focus, but the points are valid at an overall system (organization) performance level.

"The railway as a socio-technical system: human factors at the heart of successful rail engineering" (Wilson, Farrington-Darby, Cox, Bye, & Hockey, 2007) is an effort at first seemingly analogous to this research project, but done specifically on the railway as a system. This was the most comprehensive HFE/E integration into a system encountered in this literature review. The authors emphasize the need for a strong integrated ergonomics contribution at a system of systems level to engineer an improved system. They define the term ergonomics to include all aspects of the definition of the discipline provided in this proposal according to the EAI. However, by "system" they specifically speak of the railway *function* and therefore exclude its management and associated business processes, which is the intent of the present research.

This portion of the literature search proved that, although the terms "human factors", "human engineering" and "ergonomics" are by definition synonymous, "ergonomics" is

generally used specifically in reference to equipment and task design, and mostly to address physical conditions for users (e.g. to avoid workplace injuries). This review also showed that the value of people for the performance of an organization is widely recognized, as are the value and need to integrate HFE/E into business plans. Unfortunately, the papers that addressed this importance focused on workplace safety and health, limiting the potential value of the HFE/E discipline to the businesses. Some documents did address HFE/E at a broader level and emphasized the need to incorporate the discipline at a system level. In those few cases, the shortfall was the definition of "system", which was generally used to refer to a particular thing or process, and never found to include the whole organization, which was the intent of this project.

2.7 HFE/E Contribution to Knowledge Management

Enterprises have their information and knowledge in different formats (electronic documents, databases and hardcopy documents) scattered in various systems such as Product Lifecycle Management (PLM), Enterprise Resource Management (ERP), and Office Automation (OA) systems. Some of the main problems encountered in managing these valuable assets include (Huang and Diao, 2008):

- Difficulty in accumulating and maintaining knowledge during business processes. This task is usually dedicated to specialized experts, and the task becomes increasingly difficult as the quantity and variation of knowledge increases, which occurs daily.

- Knowledge workers take their knowledge when they leave the company, perhaps leaving behind documents that may be difficult for other employees to interpret and use.

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- Difficulty making use of knowledge at the start of a new project.

- Difficulty for new employees to make use of knowledge.

- Different interpretations for the same term make it difficult to share knowledge. The same words can give different meanings in different domains, cultures and backgrounds.

Many methods have been proposed to solve the above problems. Expert Systems are developed to support decision-making, standards are used for information sharing between systems, data warehouses are used to abstract useful data from large amounts of data, and now ontologies are used for knowledge management because they can provide accepted terms for different people and enterprises (Denkena and Apitz, 2003). Many large companies have resources dedicated to Knowledge Management (KM), which comprises a range of practices used to identify, create, represent, distribute and enable the adoption of what the organization "knows", and how it "knows" it. In simple terms, the focus of KM is on the management of knowledge as an asset, and the development and cultivation of the channels through which knowledge and information flow. Different organizations have tried various knowledge capture incentives, including making content submission mandatory and incorporating rewards into performance measurement plans, but there is considerable controversy over whether incentives work or not. Technologies used by knowledge management practices include expert systems, knowledge bases, various types of Information Management, software help desk tools, document management systems and other IT systems supporting organizational knowledge flows. KM programs also use organizational methods such as Communities of Practice, Networks of Practice, before-, during- and after-action reviews, peer assists, information taxonomies, coaching, mentoring... However, none of these tools or methods is able to address knowledge in

its entirety. Polanyi, chemist turned philosopher of science, created the concept of tacit knowledge, which was recorded as part of his collection of lectures, *Personal Knowledge, Towards a Post Critical Epistemology,* in 1958. He explained, among many things, that tacit knowledge is in people and functions as a background which assists in accomplishing the task at hand, that all our knowledge rests in a tacit dimension, and that we are not aware of everything we know. "Because we know more than we can tell, it follows that what has been made articulate and formalized is in some degree underdetermined by that of which we know tacitly. When we bring new words or concepts into our existing system of language, both affect each other, so the system itself enriches what the person has brought into it. We adapt new concepts in light of our experiences" (Sveiby, 1997). Barbiero (n.d.), summarizes this in the following terms: "*certain cognitive processes and/or behaviors are undergirded by operations inaccessible to consciousness".*

Nonaka and Takeuchi (1995) argued that a successful KM program needs:

- on the one hand, to convert internalized tacit knowledge into explicit codified knowledge in order to share it and,

- on the other hand, to allow individuals and groups to internalize and make personally meaningful codified knowledge they have retrieved from the KM system.

But how can internalized tacit knowledge be converted into explicit codified knowledge if we are unaware of it; if it is inaccessible to consciousness? And how can we manage (the purpose of KM) the way information retrieved from a KM system is internalized such that it serves the purpose of improving organizational performance? For these reasons, many believe KM is just not possible. Peter Drucker, one of the first people to write about the idea of the

"knowledge society" and the "knowledge economy", said at the Delphi Group's Collaborative Commerce Summit, *"You can't manage knowledge […] Knowledge is between two ears, and only between two ears."* Kotzer (2001). Frank Miller stated in an invited paper of Information Research *"Knowledge is, after all, what we know. And what we know can't be commodified. Perhaps if we didn't have the word 'knowledge' and were constrained to say 'what I know', the notion of 'knowledge capture' would be seen for what it is - nonsense!"* (Miller, 2002). Even Sveiby, one of the founders of KM, was quoted as saying "*I don't believe knowledge can be managed. Knowledge Management is a poor term, but we are stuck with it, I suppose. "Knowledge Focus" or "Knowledge Creation" (Nonaka) are better terms, because they describe a mindset, which sees knowledge as activity not an object. A is a human vision, not a technological one."* (Wilson, 2002). This does not mean that sharing knowledge and enabling people to use their creativity in innovative ways in organizations is impossible. However, this task cannot be reduced to the concept of knowledge management (Wilson, 2002). It demands something more thoughtful and understanding of what motivates and enhances the performance of human beings. Organizations need to implement practices and principles that will optimize how people perform, and this is the realm of HFE/E. Therefore, integrating HFE/E into organizations will also enhance overall organizational performance by helping improve the sharing of knowledge among employees, fomenting the best use of employee's knowledge, and enabling the use of creativity in innovative ways; in short, helping achieving those goals for which KM strives.

CHAPTER THREE: RESEARCH PLANS AND METHODOLOGY

Summarizing the major points supported by the literature review: humans are critical system components affecting overall system performance, systems can only be optimized when all system components are addressed together as one system, and the human consideration needs to be integrated within and across all system elements. When a system is defined as an organization, this means that business performance can only be optimized if, among other requirements, the people in that organization are considered to be critical elements of that organization, if people's capabilities and limitations are considered together with the remaining elements of the organization and, ultimately, if HFE/E integration is achieved throughout the organization. All of this can be accomplished by integrating HFE/E into business processes. To help businesses strive for optimal performance, the purpose of this research effort was to propose a method to integrate HFE/E into businesses, facilitating HSI and knowledge management in organizations.

A successful HFE/E integration into businesses relies on:

- a thorough understanding of business processes and related activities,

- a thorough understanding of the numerous HFE/E study areas and their relation to each other,

- and the mapping of the HFE/E discipline to business processes such that HFE/E can have a positive effect in overall business performance.

3.1 Methodology Outline

The development of a valid, accurate, and reliable method to integrate HFE/E into businesses relies on the thorough understanding of business processes and related activities, on the thorough understanding of the HFE/E many areas of study and organization of these with respect to each other, and finally on the appropriate mapping of HFE/E to business in a way that the HFE/E can provide optimal benefit to the operation of the organization. Three main research tasks were necessary to successfully accomplish the goals and objectives of this research effort; therefore, the project was divided into three parts with the following goals:

Goal of part 1 – To understand business processes and related activities.

Goal of part 2 – To understand how the HFE/E study areas relate to each other.

Goal of part 3 – To map the HFE/E discipline to business processes as applicable to enhance overall business performance.

This approach encompassed the use of a combination of taxonomy, ontology and concept mapping. These methods have been successfully used in previous research for similar purposes as those intended here. The details of these methods, their typical uses, the reasons why they were chosen, and how they were employed in this project are explained in the following sections. Figure 2 is a pictorial representation of this project's methodology, which will be described in detail in the remainder of this chapter.
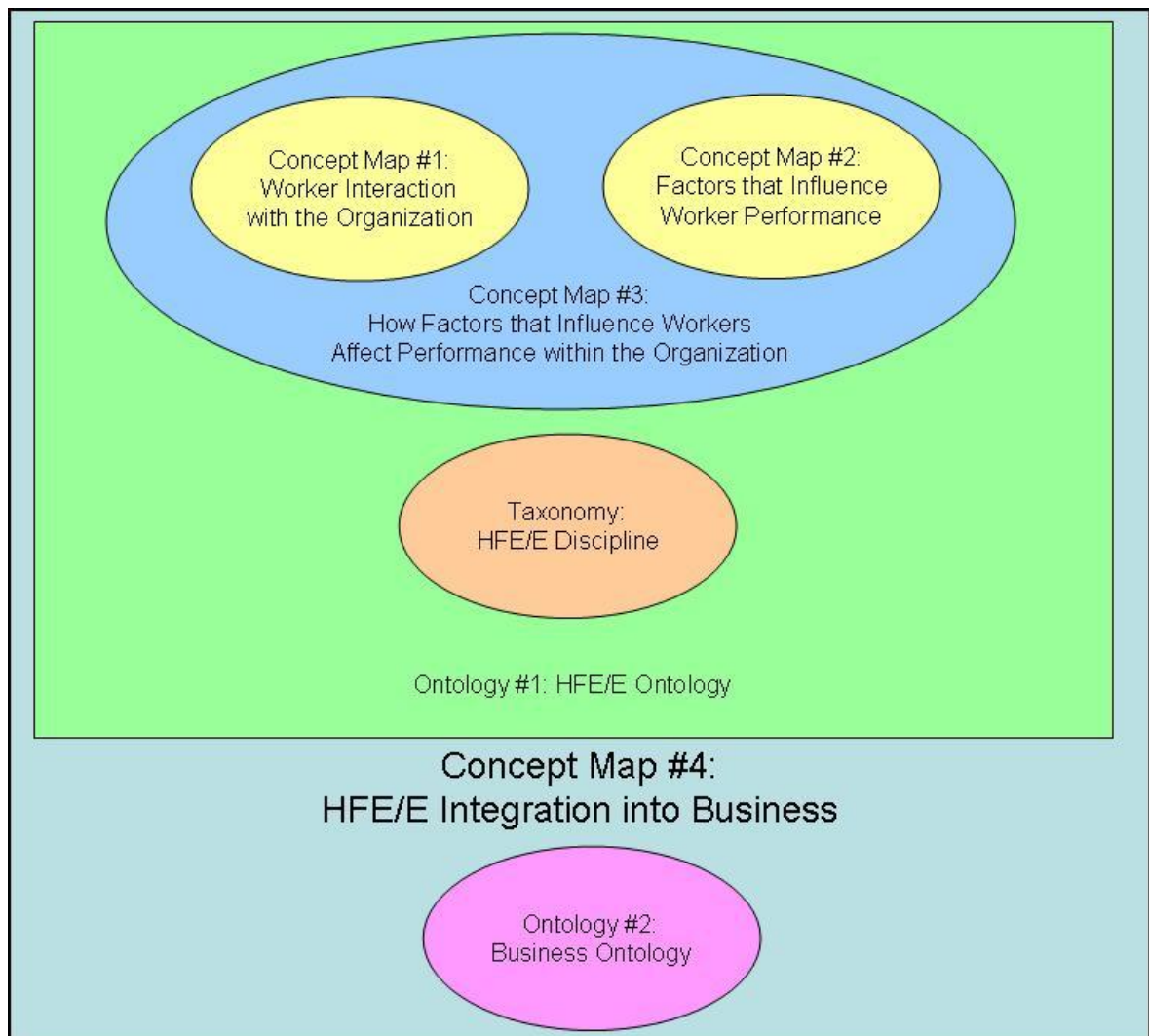
Figure 2: Pictorial representation of the research methodology.

3.1.1 The Systems Engineering Approach

Systems engineering adopts the systems approach to solving, resolving and dissolving problems. INCOSE, the International Council on Systems Engineering, provides the following definition (Hitchins, 2007):

INCOSE A. Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem. Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structure development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

This project:

- uses an interdisciplinary approach and a means to enable the realization of successful systems,

- focuses on defining customer needs and required functionality throughout the lifecycle while considering the complete problem,

- uses a structured approach,

- and considers business and technical requirements to meet user needs.

Therefore, this project adheres to the Systems Engineering approach to problem solving.

3.2 Methods Used

This subsection provides an overview of each of the three methods used in this research project. Details on specifically how each method was used are provided subsequently.

3.2.1 Taxonomy

The Encyclopedia Britannica broadly describes taxonomy as the science of classification. The term is derived from the Greek taxis ("arrangement") and nomos ("law"). Although the term taxonomy originally referred to the science of classifying living organisms, the term is now applied in a wider, more general sense and may refer to a classification of things, as well as to the principles underlying such a classification. Almost anything may be classified according to some taxonomic scheme. Taxonomy is, therefore, the methodology and principles of systematic arrangements in hierarchies of superior and subordinate groups resulting in a catalog that can be used to provide a conceptual framework for discussion, analysis, or information retrieval, so they are sometimes used as knowledge representation tools. A good taxonomy takes into account the importance of separating elements of a group into subgroups that are mutually exclusive, unambiguous, and taken together, include all possibilities.

A taxonomy was used as a stepping stone towards the construction of the HFE/E ontology and was therefore an important part of this methodology.

3.2.2 Ontology

Ontology is defined by Gruber as an explicit specification of a conceptualization of some part of reality that is of interest (Gruber, 1993a). Ontology implements strictly deductive reasoning (versus inductive or speculative reasoning). It does not involve fuzzy logic, probability-based logic, or any reasoning that attempts to simulate consciousness. More than merely a model (i.e., concepts or ideas people have in their minds), an ontology is an attempt at a true representation of the world. It is a hierarchically structured set of concepts describing a specific domain of knowledge and contains concepts, a subsumption hierarchy, arbitrary relations between concepts, and perhaps other axioms. It may also contain other constraints and functions. Within Knowledge Management, ontologies are considered broader than taxonomies as ontologies apply a larger variety of relation types. In other words, taxonomies only serve part of the purpose that ontologies do as ontologies, among other valuable information, show the relationships between concepts and concept attributes whereas the only relationships taxonomies show are children. Ontology is currently one of the better acknowledged methods to understand the structure of information otherwise difficult to grasp. In recent years, it has been adopted in many business and scientific communities as a way to share, reuse and process domain knowledge. Ontologies are now essential to many applications such as scientific knowledge portals, information management and integration systems, electronic commerce, and semantic web services. Ontologies can be used and structured in many different ways. The different ontology characteristics are largely based on the purpose of the ontology. Some of the uses of ontologies are (Noy and McGuinnes, 2001):

- To share common understanding of the structure of information among people or

    software agents

- To enable reuse of domain knowledge

- To make domain assumptions explicit

- To separate domain knowledge from the operational knowledge

- To analyze domain knowledge

Figure 3 represents the classification of ontologies suggested by Gavrilova and Laird (2005).
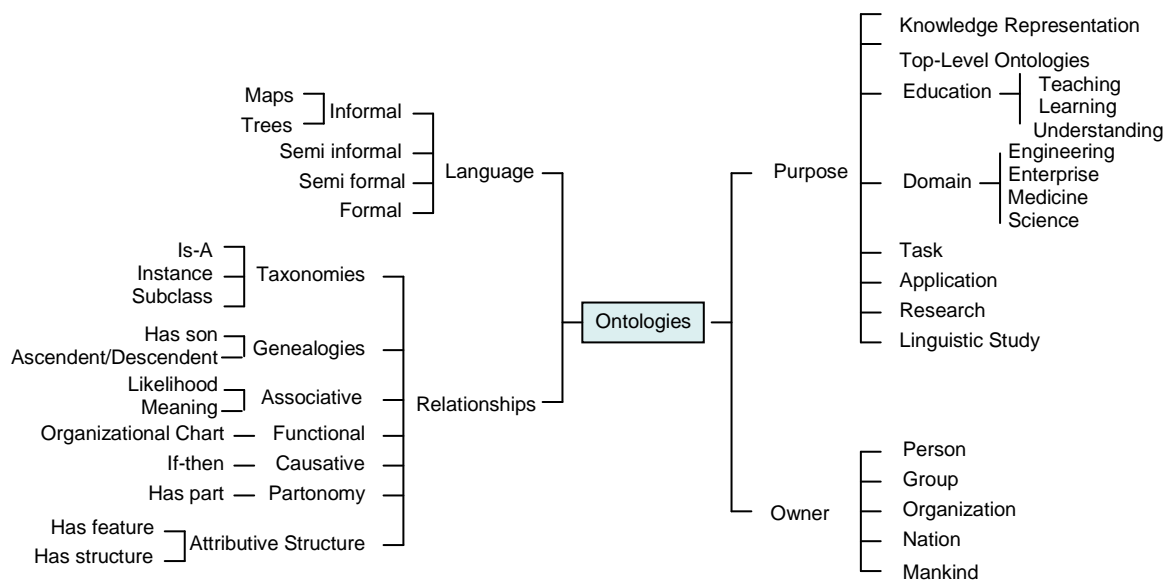
Figure 3: Ontology classification.

Both structure and formalism are also used as dimensions for classifying ontologies. Combined, these are often referred to as an ontology's "expressiveness", but descriptions on structure and formality differ. A recent attempt from the Ontology Summit 2007's wrap-up communiqué is show in Figure 4. This figure shows how ontology creates a bridge between a

domain and its content, which is the nature of ontology as one of its purposes is to try to define and bound a domain. This figure also shows the exchange between semantics and pragmatic considerations.
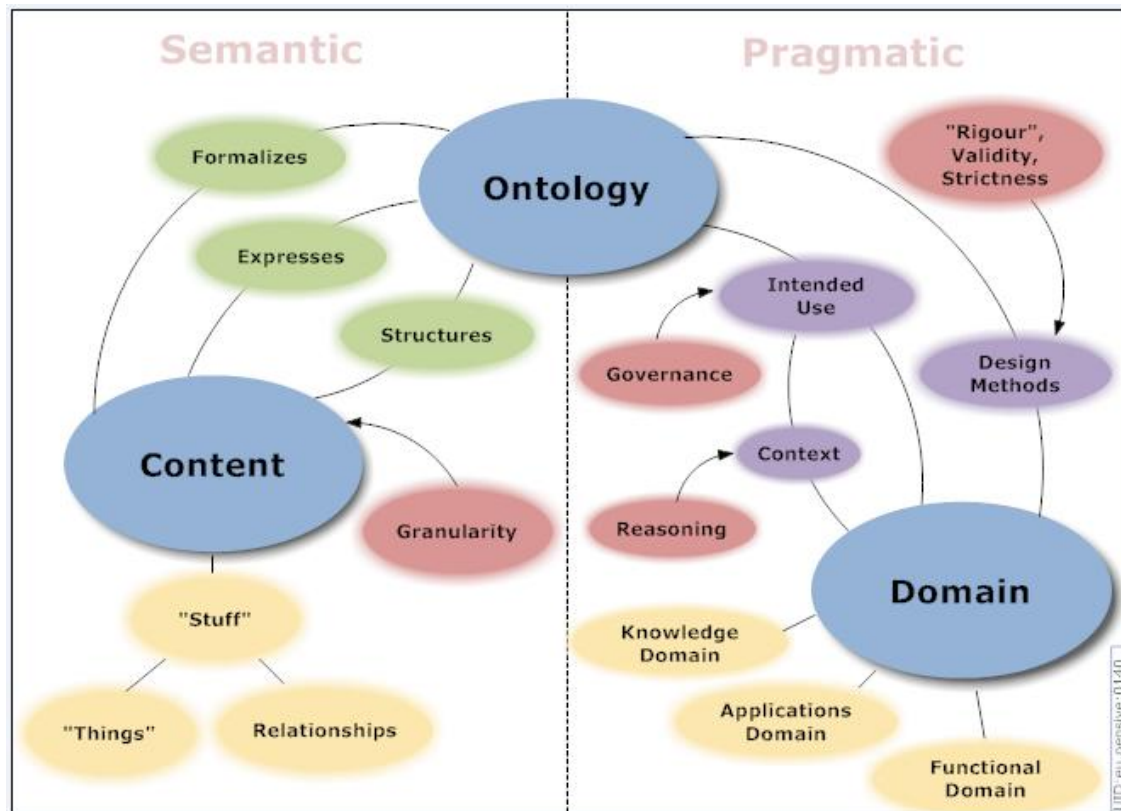
Figure 4: Map of ontology dimensions (Ontology Summit 2007's wrap-up communiqué. Used with permission of the copyright holder per http://creativecommons.org/licenses/by-nc-sa/2.5/).

Ontologies can also be characterized by levels. Specifically, ontologies are often described as being of upper, middle, or lower level. Figure 5 (Obrst, 2006) illustrates the level dimension of ontologies. Most of the content in upper-level ontologies relates to broad, abstract relations rather than more generic, common information. Figure 5 also reveals how different ontologies could relate to each other. An ontology could be, for example, a more detailed

version of another (more detailed information on the same topic) or an broader version of another (expanding on the topic of the first). The relationships and mappings among ontologies can prove very useful, and this value is well taken advantage of in this project as will be described later.
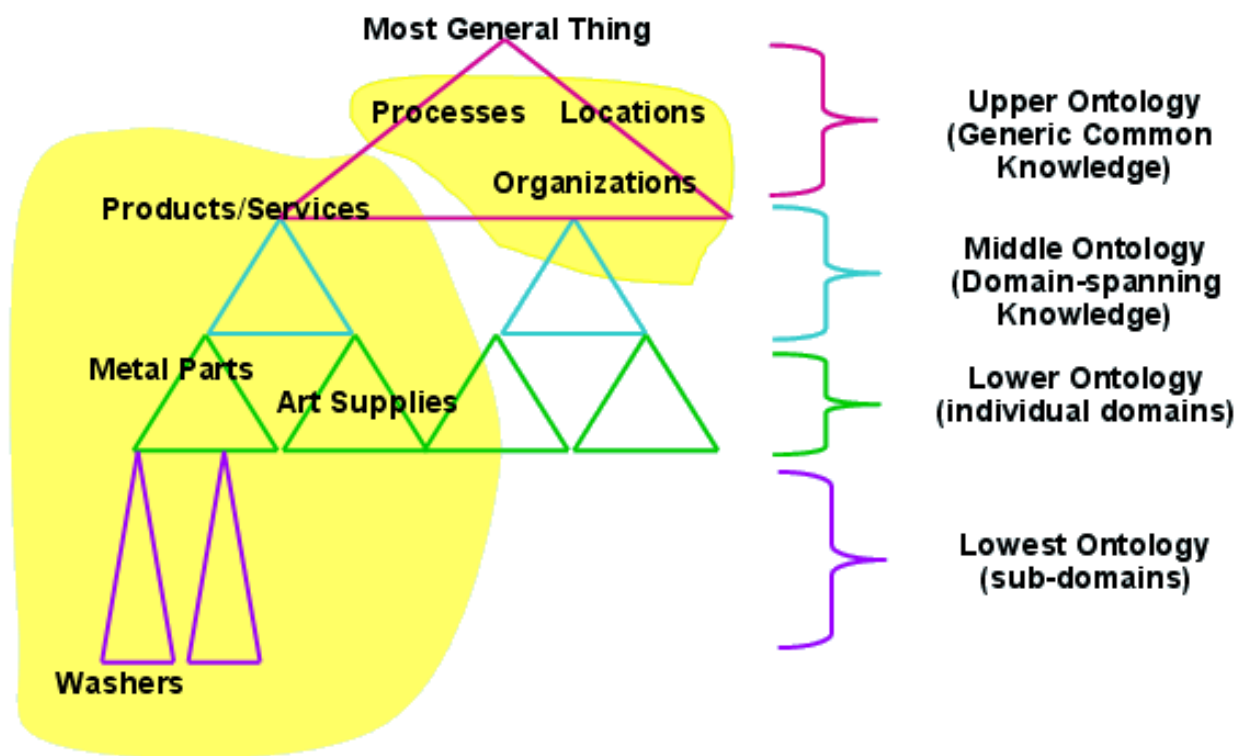
Figure 5: Ontology levels (Obrst, 2006. Used with permission of the copyright holder per http://creativecommons.org/licenses/by-nc-sa/2.5/).

This project's methodology required the construction of two specialized domain ontologies: a business ontology and a HFE/E ontology. Each ontology was used for a different purpose. The details of their construction and application are detailed in the corresponding sections below.

3.2.3 Concept Mapping

The technique of concept mapping was developed by Joseph D. Novak and his research team at Cornell University in the 1970s as a way to represent the emerging science knowledge of students. Since then, it has been used as a tool to add to meaningful learning in the sciences and other subjects, as well as to represent the expert knowledge of individuals and teams in education, government and business. The method is based on linguistics, psychology, and philosophy, and it has been accepted widely as a very useful method in education. A concept map is a tool for organizing and representing knowledge using concepts and relationships or propositions between them. It is a kind of connected and directed graph that includes two kinds of nodes: Concept Nodes and Relationship Nodes. Concept maps are used to stimulate the generation of ideas and are believed to aid creativity, so they are sometimes used for brainstorming and to communicate complex ideas. Concept Mapping can also be a stepping stone for ontology development, as it is the concepts and their relationships that are captured first into ontology if developing ontology from a concept map. Although similar, the main difference between a concept map and a mind map is that a well made concept map grows within a context frame defined by an explicit focus question, while a mind map has branches rooted on a central picture.

3.3 Building a Business Ontology for this Project

As indicated earlier, ontology can be described as a hierarchically structured set of concepts describing a specific domain of knowledge, and some of its uses include:

- Sharing common understanding of the structure of information among people or software agents

- Enabling the reuse of domain knowledge

- Making domain assumptions explicit

- Separating domain knowledge from the operational knowledge

- Analyzing domain knowledge

The first goal of this project was to understand the business processes common to any type of enterprise and the related activities, making ontology an ideal method for this goal. Therefore, it was determined that a business was ontology needed and that such ontology should be built. The business ontology was to be used for terminological purposes and also to understand the human-related activities involved in business processes. Because of the small scope of this ontology's purpose (compared to the much more complicated uses in the information technology field, for example), it was important to minimize effort and expert requirements in this task. A commonly accepted way to reduce ontology development effort is by using patterns for the ontology's construction (Blomqvist and Ohgren, 2008). The approach selected for the ontology's development was based on a method described in Blomqvist (2008), where an ontology pattern is described as a partial ontology in itself. The general idea of the method is to take existing ontology patterns to build a new ontology. Selected patterns are to be

pruned and adapted to fit their new purpose prior to including them in the new ontology. Because many knowledge sources already exist in the business domain that could be incorporated in this ontology, including already built business and enterprise ontologies, Blomqvist's suggestion was chosen as the approach to building the business ontology. Ontologies can be constructed manually or automatically. A large drawback of a manual ontology construction method is the tedious effort required. In addition, the idea of using existing ontology patterns made this ontology an excellent candidate for an automatic construction. With the goal in mind of creating the perfect business ontology for this project by reusing portions of existing ontologies, business and enterprise ontologies already developed were reviewed.

Examples of ontologies analyzed include the business and enterprise ontologies introduced by Mills Davis (2005), a strategy consultant with TopQuadrant specializing in next-wave IT, content and media technologies, and strategic envisioning. TopQuadrant's mission is to bridge the gap between business collaboration needs and enabling technology through semantic products and services including the use of ontology. However, because the company offers enterprise-level platform for developing and deploying semantic applications in particular, although insightful, these ontologies were built for a much different purpose and did not provide the level of granularity necessary to aid in this project.

The Business Concepts Ontology (BusCO) was also evaluated and became particularly valuable valuable for this project. An overview of the business concepts included in this ontology is shown in

Figure 6.
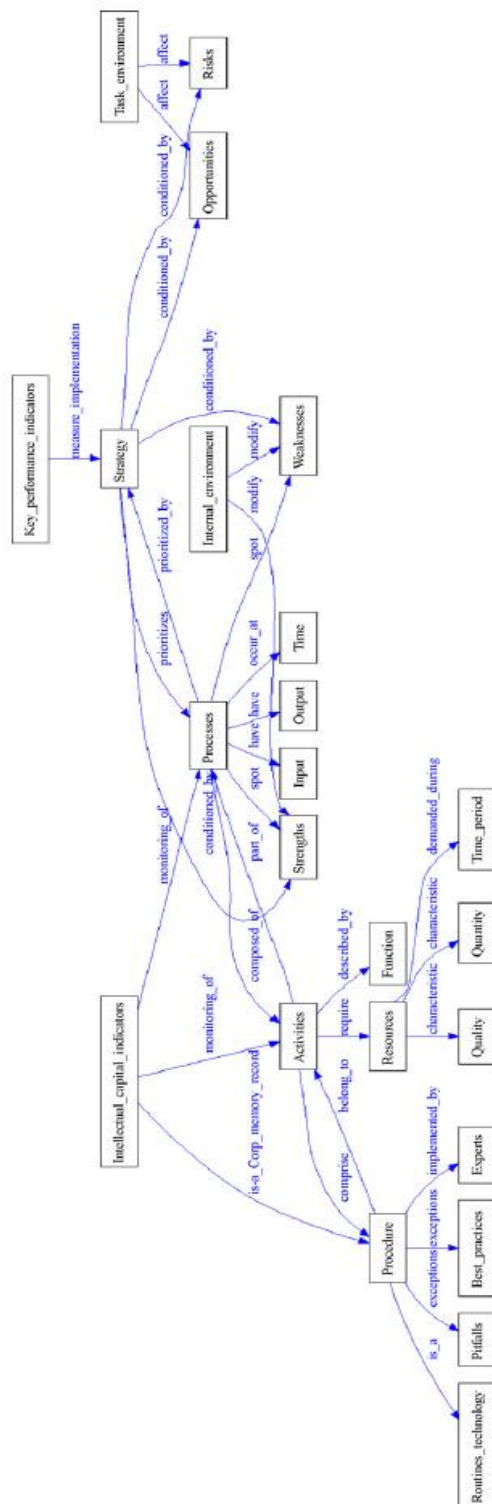
Figure 6: Overview of BusCo Concepts (Jussupova-Mariethoz and Probst, 2007. Used with permission of the copyright holder.)

The BusCO has three concept layers (Jussupova-Mariethoz and Probst, 2007):

1. Core business: represented by business processes and activities.

2. Performance indicators: key performance indicators and intellectual capital indicators.

3. Corporate memory chunks: represented by procedures.

For the purpose of this project, the more relevant portions of this ontology initially appeared to be strictly in the first concept layer: business processes and activities. Because the business ontology to be generated for this project was intended to be applicable to all types of businesses, selected processes and activities to prune from already existing business ontologies were to include only those that all businesses would have (e.g. human resources). Specialized processes and activities were therefore to be excluded since the ontology could always be expanded to include additional processes and activities if the new ontology were to be customized for specific types of businesses.

The logic of the chain of the BusCO core business concept layer (i.e., the enterprise's processes and activities) takes into consideration the following aspects:

- When a process or an activity should be initiated and finished.

- Who participates in the process or activity.

- How the process or activity should be performed.

This information comprised the information originally considered sufficient from a business ontology to accomplish this project's objective of mapping HFE/E to business processes. However, the following paragraphs and subsections will make evident and elaborate

on why additional considerations are necessary in a business ontology for a successful HFE/E integration.

Important definitions were provided with the BusCO (Jussupova-Mariethoz and Probst, 2007). A "process" is defined as a sequence of actions resulting in a product or service. The "process" is composed of "activities". Each process can be characterized by a unique value-added contribution to the enterprise business cycle. Examples of processes are "design products and services" and "manage organizational changes". An "activity" is a set of procedures, competences and resources brought together for achieving a specific purpose or implementing a specific function. Activities determine the means and tools used to successfully implement the enterprise strategy. Activities may be classified as primary or secondary according to their contribution to the departmental goals. They may also be classified as core, support or diversionary activities according to their contribution to the enterprise goals, competitive advantage or responsiveness to the deficiencies in the business-to-customer relation.

Definitions relevant to the third BusCO concept layer were also reviewed and found of significance for this project. A "procedure" is used to indicate a standard method of completing an activity. Procedures are of great consequence because, when carried out, they create new knowledge on one hand (at the very least for the person using the procedure), and on the other hand they reuse enterprise knowledge. Procedures include the collection of best practices, lessons learned or pitfalls, and observations; and they relate to strategies, processes and/or activities. They may rely more or less on the knowledge of the actors depending on how much user discretion is permitted. The definition of procedure clearly indicated the importance of this concept in the HFE/E context as the HFE/E discipline can be applied to make procedures, as two of multiple possible examples, more efficient and less likely to contribute to human error,

impacting the organization's overall performance. Rather than addressing specific procedures individually, it was decided to group procedures together and later map HFE/E specialties to this concept as a group. For this reason, it was still determined that the business ontology did not need to go below the second concept layer (at the level of the business activities) and reach the third layer (procedures). Procedures, however, would need to be a concept in the business ontology developed for this project due to its obvious relevance to HFE/E in terms of contribution to business performance.

Also in the BusCO, an ''Actor'' is defined as being one of two types: a human or a software tool. Human competences including knowledge, skills, behavioral characteristics, etc. may be analyzed and classified in different ways, but the description of the concept ''Actor'' for a human always includes personal data and job title. To avoid the data overflow, BusCO only includes competences relevant to the person's position or to the case. In addition, each actor has a different level of decision power.

The definitions described above were also found in other business ontologies, some with slight differences mainly in the level of detail of the definition. The most important differences will be highlighted as they arise since often they elucidate reasons why this project evolved the way it did.

Many companies use information systems such as Enterprise Resource Planning, Customer Relationship Management, and Workflow Management Systems (WFMS) to support the execution of their business processes. Our competitive world requires companies to adapt their processes at a very fast pace, needing continuous and insightful feedback on how business processes are executed. A Core Ontology for Business pRocess Analysis (COBRA) was developed by Pedrinaci et Al. (2008) to serve this purpose (Figure 7). COBRA was also

reviewed for this project. It primarily characterizes business activities from the standpoint of the persistent entities involved. COBRA aims to cover the Resource and Object views typically adopted in Business Process Analysis (BPA). BPA is typically structured around three different views (zur Muehlen, 2004):

1. The process view, concerned with the performance of processes and mainly focused on their compliance with expectations and Key Performance Indicators. The purpose is to support business analysts in the effort to optimize processes in place (van der Aalst et Al., 2007). Information considered includes "functioning processes and activities"; "which ones have been completed and their success"; "the execution time of the different business activities", etc.

2. The resource view is centered on the usage of resources within processes. Aspects analyzed under this view include performance at different levels of granularity (individuals, organizational units, etc.), work distribution among the resources, and optimization in the use of resources. Typical questions would be, for example, "which resources were involved in which business activities"; "which actor was responsible for a certain process"; "which external providers appear to work more efficiently"; "what's the average number of orders processed by the sales department per month", etc.

3. The object view focuses on business objects such as inquiries, orders or claims. This perspective is often implemented to analyze the life-cycle of Business Objects. Questions typically answered would be "what is the average cost per claim"; "which is the item we are currently selling the most (or the least)"; "what's the overall benefit we are obtaining per item"; "are critical orders processed in less than two hours", etc.

The COBRA approach is based on the notion of Role, which is defined as the function assumed or part played by a persistent entity in the performance of a particular business activity. The Role function is another important concept in this project's business ontology as it provides information about Actor during the performance of an Activity. This importance will be expanded upon later.

Figure 7: Core Business pRocess Analysis (COBRA) ontology (Pedrinaci et al., 2008. Used with permission of the copyright holder).

Another ontology reviewed was the context-based enterprise ontology *(*Leppänen, 2007), which is intended to assist in the acquisition, representation, and manipulation of enterprise knowledge. It is a top-level ontology that aims to advance the understanding of the nature, purposes, and meanings of the things in the enterprise. A thing gets its meaning through the

relationships it has with the other things in that context. Individual things are considered to play specific roles in a context, and/or to be contexts themselves as applied to, in this case, the enterprise. The contextual approach upon which this ontology is based involves seven domains: purpose, actor, action, object, facility, location, and time (Figure 8). These domains help specify and interpret contextual phenomena. The ontology provides basic concepts for conceiving, structuring and representing things within contexts and/or as contexts: *For Some* purpose, *Somebody* does *Something* for *Someone,* with *Some* means, *Sometimes* and *Somewhere*. In this ontology, Enterprise is defined as a group of contexts composed of people, information and technologies, all performing functions in the defined organizational structure for agreed purposes, and all responding to both internal and external events and to the needs of stakeholders.
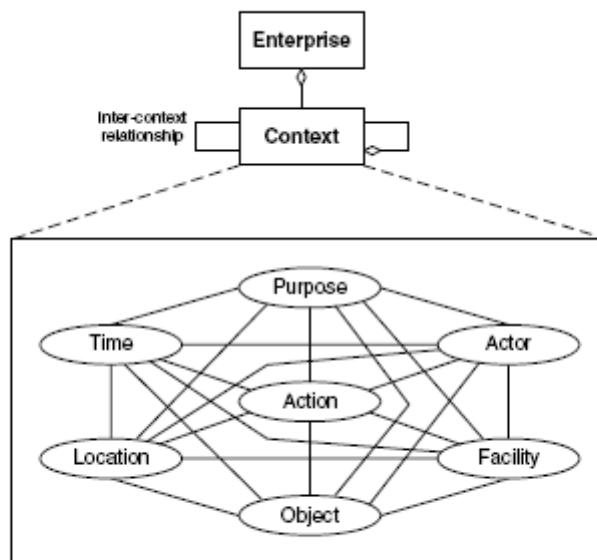
Figure 8: Overall structure of the context-based enterprise ontology (Leppänen, 2007. Used with permission of the copyright holder).

The actor domain consists of the concepts and constructs that refer to human and other active

active parts in a context (

Figure 9). The following are definitions of the components of the actor domain within

the context-based enterprise ontology.

An *actor* performs actions in contexts and can be human (an individual or a group of

persons) or non-human.

A *person* is a human being, characterized by desires, intentions, social relationships, and

behavior patterns conditioned by his or her culture (Padgham & Taylor, 1997), and may be a

member of none or numerous groups.

A *position* is an employment station occupied by none or many human actors. Each

position specifies qualifications in terms of skills and demands on education and experience.

An *organizational role* is a collection of responsibilities predetermined operationally or

structurally. If predetermined operationally, the role consists of tasks that a human actor

occupying the position with that role is needs to perform. If predetermined structurally, the role

is responsible for objects. A role can be played by several persons and may or may not be linked

to the position(s) they hold.

The *supervision relationship* engages two positions: a supervisor and a subordinate. A

supervisor position is required and authorized to make decisions related to the positions of its

subordinate(s). Subordinate positions are required to report to their supervisors on the work and

results.

An *organization* is a purposeful administrative arrangement indicating how the work is

divided into actions and the coordination of actions to accomplish the work. It can be permanent

and formal or temporally established like a project organization for very specific and short-term

purposes. An *organizational unit* comprises positions with the established supervision relationships. Organizational units constitute an organization.
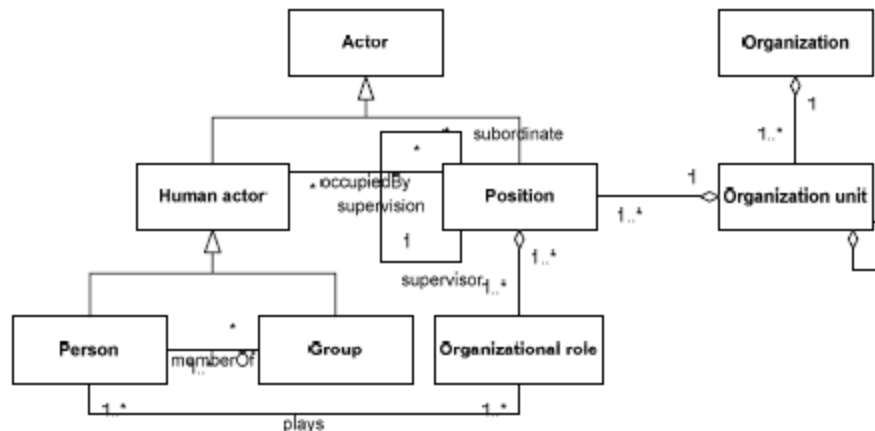
Figure 9: Actor domain (Leppänen, 2007. Used with permission of the copyright holder).

The *action domain* (Figure 10) encompasses concepts and constructs referring to actions or events in a context. An *Action* can be independent or collaborative and may range from the physical execution of a step-by-step procedure with detailed routines, to strategic planning. An action is a part of an action structure. There are four orthogonal action structures: the decomposition structure, the control structure, the temporal structure, and the management – execution structure.

- In the *decomposition structure,* actions are divided into sub-actions, sub-action are divided into sub-sub-actions, and so forth until the lowest level of elementary actions is reached. Parts of actions are functions, activities, tasks or operations.

- The *control structure* indicates the way in which the actions are logically related to each other and the order in which they are to be executed. There are three control structures:

sequence, selection, and iteration. The *sequence relationship* is self explanatory: action 2 follows action 1. The *selection relationship* means that there is a set of alternative actions from which one specific action is to be chosen. The *iteration relationship* indicates that an action is repeated after completion. Repetition continues until stated conditions become true.

- The *temporal structures* are like the control structures but with time-related conditions and events. They permit specifying overlapping, parallel and disjoint (non-parallel) actions. The *management – execution structure* is composed of one or more management actions as well as execution actions that are the result of orders received from the management actions. *Management actions* include *planning, organizing, leading* and *controlling* (Griffin, 2006). Leading in this framework is divided into *staffing* and *directing. Execution actions* aim to implement plans and orders by means of given resources.

Action structures are enforced by rules. A *rule* is a principle or regulation governing a conduct, action, procedure, arrangement, etc. (Webster, 1989). A collection of related rules compose a *work procedure*, which prescribes how actions should be carried. Work procedures may be defined at different levels of detail.

Understanding these definitions was important and of relevance in this project because the HFE/E discipline can influence all of the described domains and therefore affect the enterprise's overall performance. The descriptions of the context-based enterprise ontology domains provided above are not comprehensive. They were intended to show the complex

relationships between ontology concepts and the important differences between seemingly similar concepts.

Figure 10 through Figure 12 represent three additional domains of the context-based enterprise ontology: the action domain, the object domain and the facility domain respectively. Descriptions are not included as there is no need for the purpose of this section. References to the figures will be made and descriptions will provided when necessary.
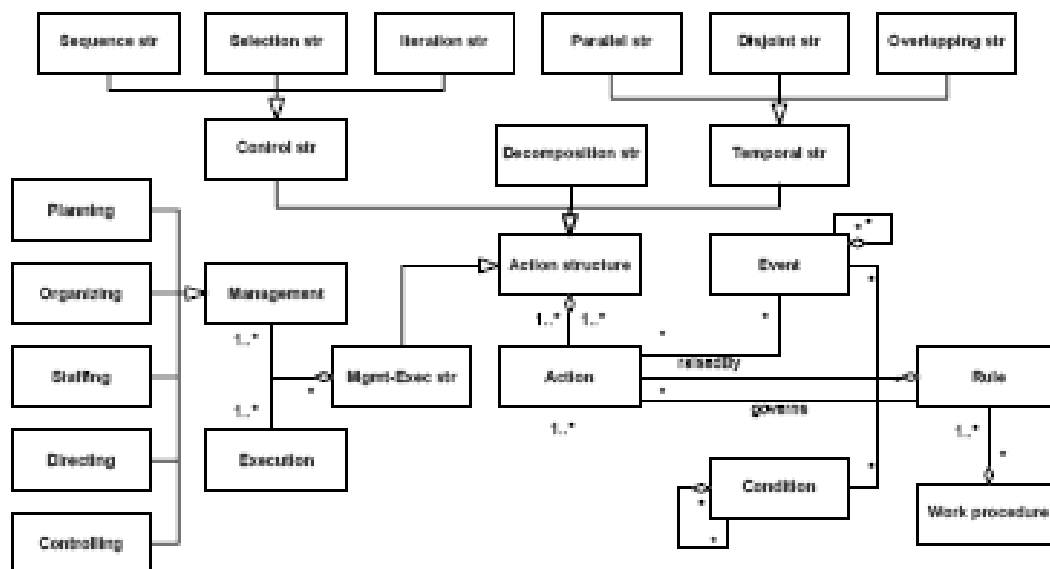
Figure 10: Action domain (Leppänen, 2007. Used with permission of the copyright holder).
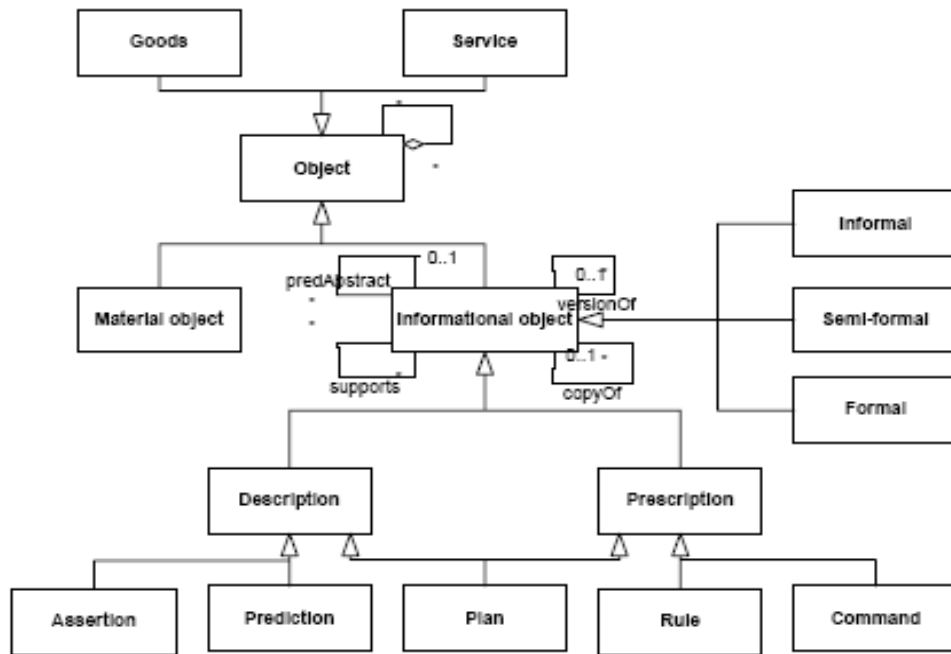
Figure 11: Object domain (Leppänen, 2007. Used with permission of the copyright holder).
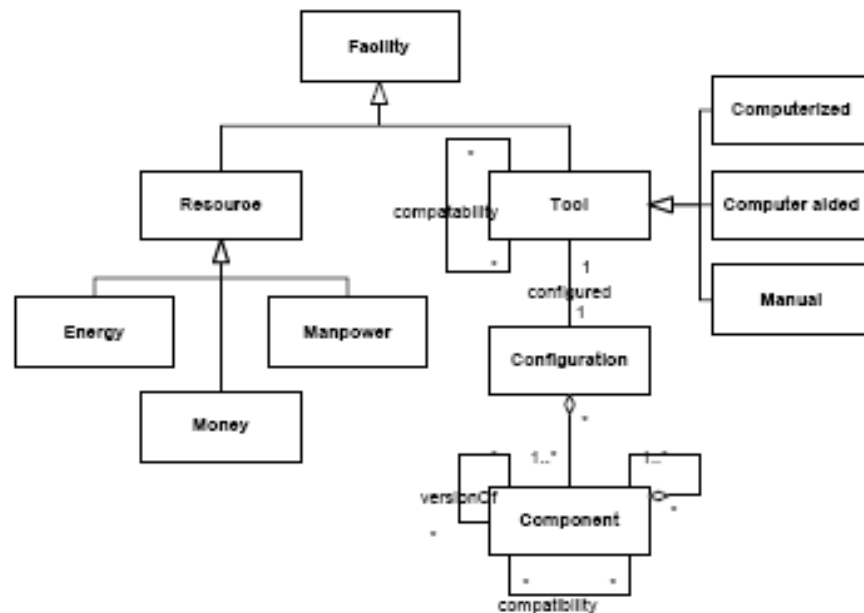
Figure 12: Facility domain (Leppänen, 2007. Used with permission of the copyright holder).

One more enterprise ontology approach evaluated was the Design and Engineering Methodology of Organizations (DEMO), proposed by Dietz and Hoogervorst (2008), based on the Ψ-theory of Dietz and Albani (2005). In the Ψ-theory, humans in a system perform two kinds of acts:

- *production* acts (P-acts), in which humans contribute to bringing about the goods or services that are delivered to the environment. These acts can be material (e.g., manufacturing and transporting goods) or immaterial (e.g., granting insurance claims and selling goods).

- *coordination* acts (C-acts), in which humans enter into and comply with commitments towards each other regarding the performance of P-acts. C-acts result in both the performer and the beneficiary of the acts getting involved in commitments about the corresponding P-act. C-acts do not require the involvement of oral or written communication; they could be performed by a non-verbal acts such as a nod. More importantly, C-acts may be performed tacitly, such that there is no actual act that could be considered as the performance of the act. Tacit C-acts must be understood as being agreed upon during a transaction, whether implicitly or explicitly.

The DEMO approach uses the term *actor role,* which is defined as having the authority and responsibility to be the performer of a type of transaction. Actor roles are fulfilled by subjects. An actor role may be fulfilled by several subjects, and a subject may fulfill several actor roles. In general, actor roles are not directly linked to common organizational units or functions. DEMO defines *actor* a subject in its fulfillment of an actor role.

In short, the DEMO approach also brought to light important considerations for the integration of the HFE/E discipline into business processes.

As illustrated, ontologies are built differently and focus on different aspects (affecting definitions) depending on their purpose. One similarity found in ontologies built to analyze

business processes was that those ontologies are typically structured around the process, resource, and object perspectives. Also common to the ontologies where business processes are analyzed is the underlying dependency on actors. These Actors perform Actions, which is how Procedures are completed following Rules and so forth. The differences in definitions and descriptions of each of the business ontologies evaluated provided information that, when combined and considered from the HFE/E's application to business performance perspective, helped develop a more efficient and probably effective method for the HFE/E integration into businesses. Taking these combined pieces of information into account, a series of business ontology concepts appeared to be particularly relevant to HFE/E. This finding provoked the idea that, in order to make this project's outcome as generalizable as possible, it would be best to identify ontology concepts that are common to all business ontologies but specifically relevant to HFE/E and create the business ontology based strictly on those. This ontology could then be merged with the HFE/E ontology built in this project to illustrate the integration of this discipline within business concepts. The product of this combination would be able to be "plugged" into any existing business ontology using the newly created ontology business concepts as "plugs".

The business concepts selected for this project's business ontology were, in alphabetical order: Action, Activity, Actor, Competence, Descriptive Information, Facility, Function, Group, Human Actor, Information, Non Human Actor, Organization, Organizational Unit, Position, Prescriptive Information, Procedure, Process, Product, Purpose, Resource, Role, Rule, Service and Tool. The rationale for the selection of these critical business concepts for HFE/E integration is explained in the section describing the integration of HFE/E into business processes. The business ontology generated with these business concepts is shown in Figure 13.
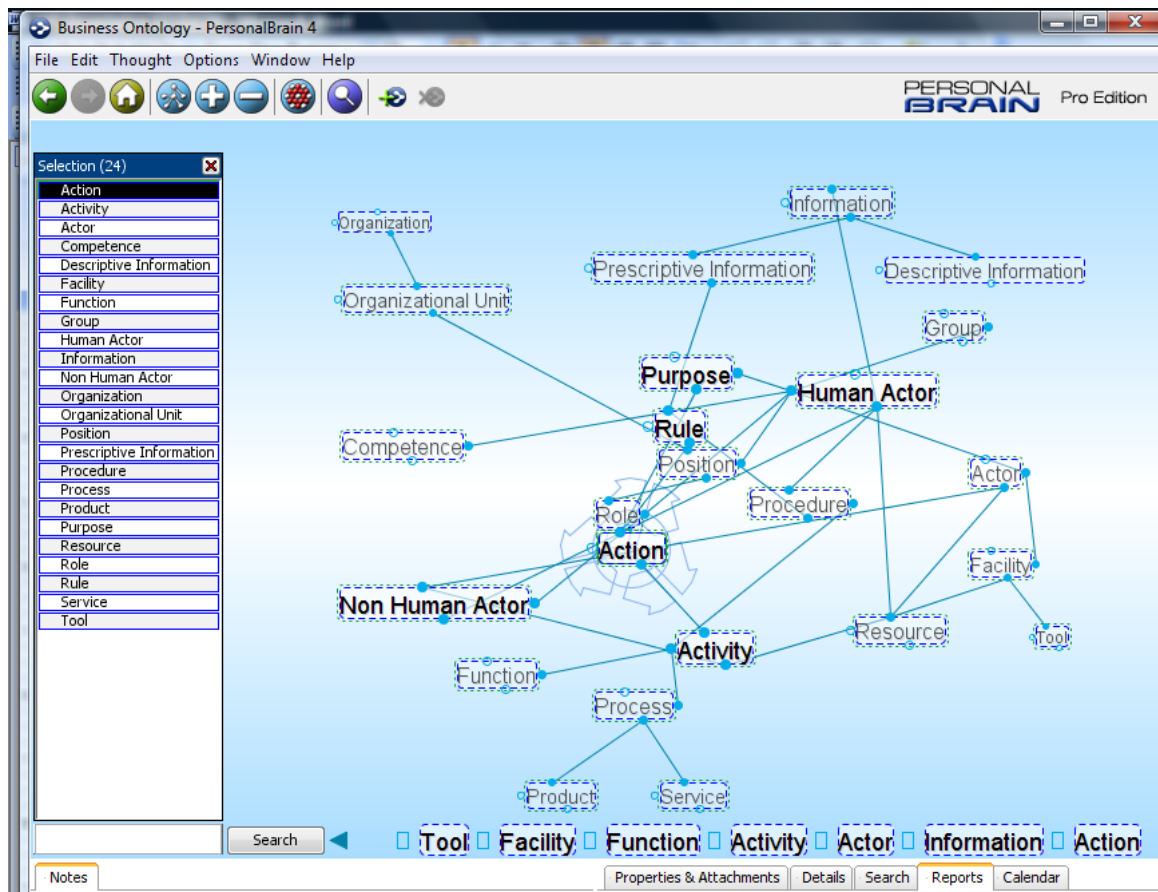
Figure 13: Business ontology generated to enable a practical HFE/E integration into organizations.

Definitions for the business concepts of this particular ontology are described next:

Action.   Actions are performed by actors.   They range from physical step-by-step executions to strategic planning, include communication, and may be determined by rules. Actions may or may not (in the case of unintentional actions) have a purpose and are composed of activities.

Activity.   A set of procedures, competences and resources brought together for performing an action and implementing a function.

Actor. Human or non human capable of performing an action.

Competence. Human competence defines a human actor's readiness for the job.

Descriptive Information. Information determined by a plan, assertion and prediction.

Facility. Physical location where work takes place.

Function. Part of an action and implemented by activities.

Group. More than one human actor.

Human Actor. A person who performs actions under specific roles (maybe more than one) and with designated decision power. A human actor occupies a position, is characterized by internal factors that affect his/her performance, and may be a member of none or numerous groups.

Information. Facts, data, instructions or other communication in any medium or form.

Non Human Actor. Object capable of performing an action (e.g. computer).

Organization. Group of organizational units.

Organizational Unit. Group of positions.

Position. An employment station requiring specific qualifications and occupied by none or several human actors.

Prescriptive Information. Information determined by a plan, rule or command.

Procedure. A standard method of performing an activity allowing more or less flexibility on the part of the actor depending on the degree of user discretion permitted. A procedure is composed of related rules.

Process. A sequence of actions composed of activities resulting in a product or service.

Product. Possible result of a process.

Purpose. The reason for intended actions.

Resource. Physical (as in tools) and non physical (as in information) source of supply or support. Includes human actors.

Role. A collection of responsibilities specifying the part played by an actor in the performance of an activity and allowing a certain degree of authority. Several human actors may perform the same role. Roles are not necessarily linked to positions, functions, or organizational units, but they may be. Roles provide the authority and responsibility to be the performer of a type of transaction.

Rule. Rules enforce actions and procedures.

Service. Possible result of a process

Tool. An aid to accomplishing a task.

This section has not been all-inclusive of business ontology domain or concept definitions. The purpose of the descriptions and definitions included was to explain how business ontologies were used in this project. Special attention was given to information particularly relevant to HFE/E, especially details that are considered useful to understanding the links that were created during the integration of HFE/E to business concepts.

3.4 The HFE/E Ontology

The second goal of this project was to understand how all of the HFE/E study areas relate to each other. Since ontology is a form of knowledge representation about a domain and can be used to define that domain, it was also selected as the method to structure the HFE/E discipline's areas of study. Having a HFE/E ontology would also make the task of proposing HFE/E areas to integrate into businesses a more practical one, and the actual integration process more clear and structured, as will be explained later. Because in this case, unlike with the business domain, no previous HFE/E ontology existed, one had to be created from scratch. Also due to the lack of existing HFE/E ontologies, although of the two ontology construction methods suggested by Blomqvist and Ohgren (2008) the manual method has the large drawback of requiring tedious effort, using an automatic method was not an option. The approach to achieving the goal of this part of the project was, therefore, to manually create the HFE/E ontology.

As experienced in the business ontology case, determining the purpose and scope of the ontology to be built greatly affects further decisions in the ontology development process. This would also be a specialized domain ontology: a HFE/E ontology to be used for terminological purposes and to generate a single comprehensive structure showing the relationships among the numerous study areas of the HFE/E discipline. The ontology needed to be comprehensive, at an application level intended for structuring and describing HFE/E information, and should be useful for creating a HFE/E knowledge base later on (not part of the scope of this project).

As in the business ontology case, the scope of this ontology's purpose was small compared to the complex applications of ontology in the computer science and information technology fields. Therefore, it appeared possible to make the HFE/E construction process

relatively simple as long as 1) existing HFE/E knowledge sources such as models and taxonomies were well taken advantage of, 2) the ontology was built only to the necessary level of complexity, and 3) the right tool was used for the ontology's construction. How each of these important considerations was taken into account is briefly described in the remainder of this section and elaborated upon in the appropriate sections.

Although no HFE/E ontologies exist and no standard for grouping HFE/E areas of study into categories exists, efforts have been expended in textbooks, encyclopedias, and other publications such as collections of work like the Ergonomics Abstracts to categorize this discipline's specialty areas. For example, as explained in the literature review, the IEA classifies HFE/E into three domains. Each of the domains addresses specific HFE/E topics:

- Relevant topics of the physical ergonomics domain include working postures, materials handling, repetitive movements, work related musculoskeletal disorders, workplace layout, safety and health.

- Relevant topics of cognitive ergonomics include mental workload, decision-making, skilled performance, human-computer interaction, human reliability, work stress and training as these may relate to human-system design.

- Relevant topics of organizational ergonomics include communication, crew resource management, work design, design of working times, teamwork, participatory design, community ergonomics, cooperative work, new work paradigms, virtual organizations, telework, and quality management.

These categorizations and other existing HFE/E resources were used to ensure consistency with accepted terms, definitions, taxonomies, etc., and to avoid disagreements and unnecessary rework.

Noy and McGuinnes (2001), from Stanford University, present a step by step guide on how to build an ontology. They begin by providing the following definition of ontology which, conveniently, clarifies some of the necessary terminology: An ontology is a formal explicit description of concepts in a domain of discourse (classes (sometimes called concepts)), properties of each concept describing various features and attributes of the concept (slots (sometimes called roles or properties)), and restrictions on slots (facets (sometimes called role restrictions)).

They divide the project of building an ontology in the following major tasks:

- defining classes in the ontology,

- arranging the classes in a taxonomic hierarchy,

- defining slots and describing allowed values for these slots,

- filling in the values for slots for instances.

A knowledge base is also defined by Noy and McGuinnes as an ontology together with a set of individual instances of classes. Because this HFE/E ontology did not need to reach the knowledge base level, individual instances would not need to be generated.

The main tasks just listed are further divided into a step-by-step guide as follows:

Step 1. Determine the domain and scope of the ontology.

This can be done answering the following basic questions:

- What is the domain that the ontology will cover?

- What is the purpose of use of this ontology?

- Who will use and maintain the ontology?

- What types of questions should the information in the ontology be able to answer? These questions serve as a litmus test later in the project to help determine if the ontology contains enough information. At this point, however, the purpose of the questions is to determine the types and categories of information are required.

Step 2. Enumerate important terms in the ontology.

This involves listing important terms to either make statements about or explain to the ontology's user, along with the terms' properties. Initially, this list it brainstormed without considering possible overlaps, relations among terms, or types of terms.

The next two steps are the most important in the ontology design process. They are closely intertwined and are therefore performed in parallel.

Step 3. Define the classes and the class hierarchy.

Terms that refer to independent objects (versus terms that describe these independent objects) are selected from the list created in Step 2. These terms become classes in the ontology and will constitute anchors in the class hierarchy. Classes are then organized into a hierarchical taxonomy. A combination of top-down and bottom-up development process approaches would be used in this project. The most general concepts in the domain would be the first to be defined, and those would be broken down into more specialized concepts (top-down). However, after reaching a certain point, very specific classes would be grouped into more general concepts and placed as deemed appropriate in the hierarchy (bottom-up).

Step 4. Define the properties of classes – slots.

Because the classes do not provide enough information to answer the competency questions from Step 1, the internal structure of concepts must be described. Classes were already

selected from the list of terms created in Step 2, so most of the remaining terms would probably be properties of these classes. This step consists on identifying the class which each property describes. The properties later become slots attached to the corresponding classes.

Step 5. Define the facets of the slots.

Slots can have different facets describing the value type, allowed values, the number of the values (cardinality), and other features of the values the slot can take. Facets will be defined for each slot as defined next:

- **Slot cardinality** defines how many values a slot can have (it can be a single or multiple values).

- **Slot-value type** describes the types of values that can fill in the slot. The more common value types include:

  - **String:** the simplest value type used for slots.

  - **Number** (more specific value types like Float or Integer may be used) describes slots with numeric values.

  - **Boolean** slots are simple yes/no flags.

  - **Enumerated** slots specify a list of specific allowed values for the slot.

  - **Instance**-type slots allow a definition of relationships between individuals. Slots with value type Instance must also define a list of allowed classes from which the instances can come.

- **Domain and range of a slot are a**llowed classes for slots of type Instance.

Step 6. Create instances.

This step consists of, first, selecting a class, then creating an individual instance of that class, and finally filling in the slot values.

Although the steps just listed were intended to help beginners build an ontology, they clearly reached a level unnecessary for the purpose of this HFE/E ontology.

Blomqvist and Ohgren (2008) also suggest an ontology construction process that seemed more adequate for the needs of this project:

1. Produce a user requirements document including the identification of existing knowledge sources and usage scenarios, users, purpose, and scope.

2. Build a simple concept hierarchy based on the available relevant domain documents, and generate natural language descriptions for each concept when deemed necessary.

3. Derive relations, constraints, and axioms from the documents or from interviews if necessary.

The described guidelines along with other documents and tutorials reviewed, all listed in the bibliography (e.g., Gavrilova and Laird (2005) and Smith (2003)), were used to formulate the HFE/E ontology development process, which is explained in the next section.

Finally, as explained, choosing the right tool to build the ontology was critical in minimizing technological effort and software expert requirements. Several potential software tools were identified, of which only a few were seriously considered. The most important characteristics were usability for a new user and beginner in ontology development, interface (visual rather than code), flexibility (not forcing more detail than that needed for this project), industry recognition and cost. The candidates and the finally chosen tool are described later.

3.4.1 Building the HFE/E Ontology

All of the sources of information reviewed on how to build an ontology agreed in that the first thing that must be determined is the purpose and scope of the ontology to be created. One of the ways to determine the scope of the ontology is to prepare a list of competency questions which a knowledge base built on the ontology would be able to answer (Gruninger and Fox, 1995). The competency questions should allow determining whether the proposed ontology covers properly the chosen domain. These competency questions do not need to be exhaustive (Noy and McGuinness, 2001). Therefore, the domain and scope for the HFE/E ontology were elaborated on as follows:

- What is the domain that the ontology will cover? The HFE/E discipline.

- What is the purpose of use of this ontology? This ontology will serve a dual purpose. It will be used to gather and structure all of the HFE/E study areas and to help non domain experts understand what the HFE/E discipline entails. The ontology will also be used for the application of integrating HFE/E into business processes, which will require non domain experts understand how HFE/E affects how businesses function.

- Who will use the ontology? HFE/E experts planning a HFE/E integration into organizations or preparing to do so, and non HFE/E experts who are part of an organization considering, planning, or performing a HFE/E integration into the organization. Possible users may also be those interested in learning about the HFE/E discipline or HFE/E experts who want to use this ontology as a thinking tool.

- What types of questions should the information in the ontology be able to answer? Examples of questions the ontology should be able to answer are:

- o How does a person's knowledge of procedures affect his/her job performance?

- o What are important HFE/E considerations for a person to be able to take the correct action in his/her role?

- o What management factors affect a person's decision making?

The approach to building the HFE/E ontology consisted on combining three concept maps and a taxonomy. Figure 14 is a pictorial representation of the methodology. The reason for the selection of these particular concept maps and taxonomy and their descriptions are explained next.
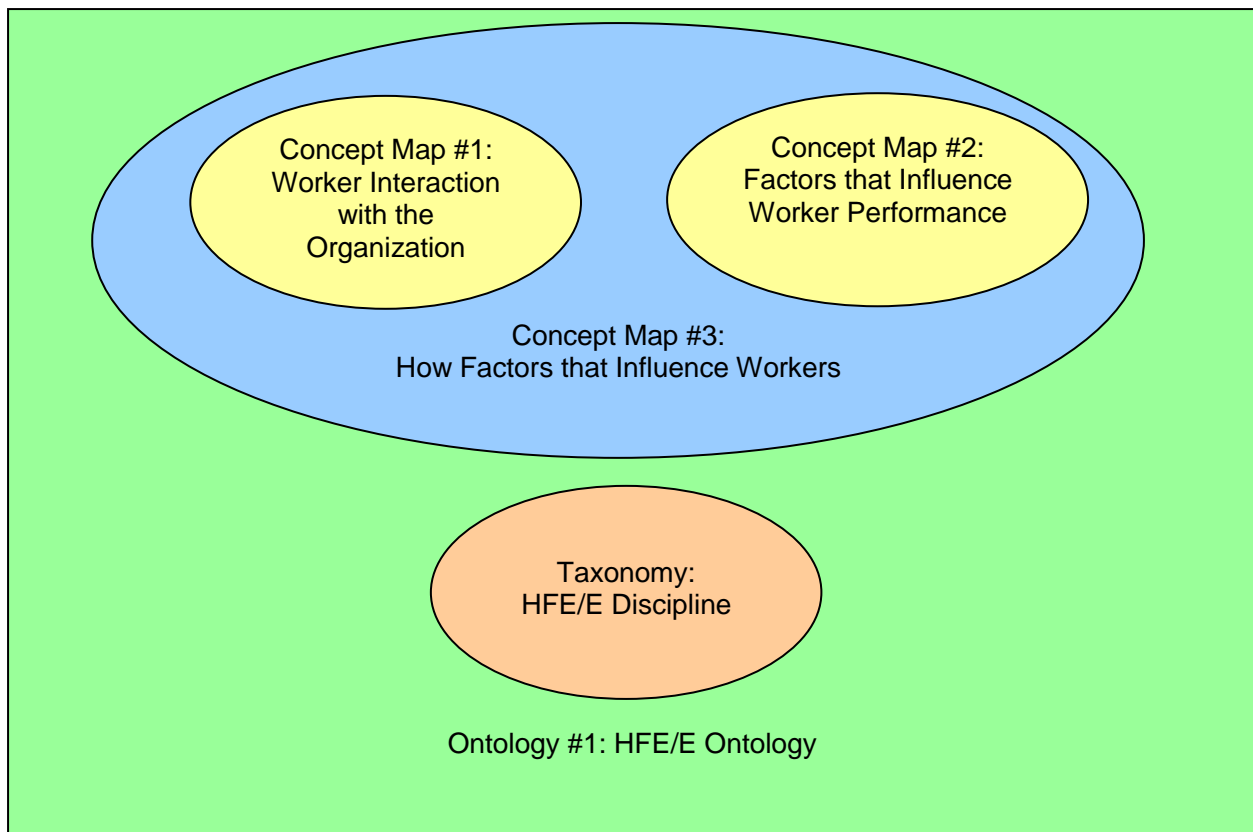
Figure 14: HFE/E ontology building methodology.

Humans interact with all of the components of the organization. David Meister presented a model depicting how humans and systems interact in *Human Factors: Theory and Practice*, 1971. This model has since been adapted to add environmental influences on that interaction. The model illustrates the typical interaction between the human and machine components of a system. Figure 15 is a depiction of this model.
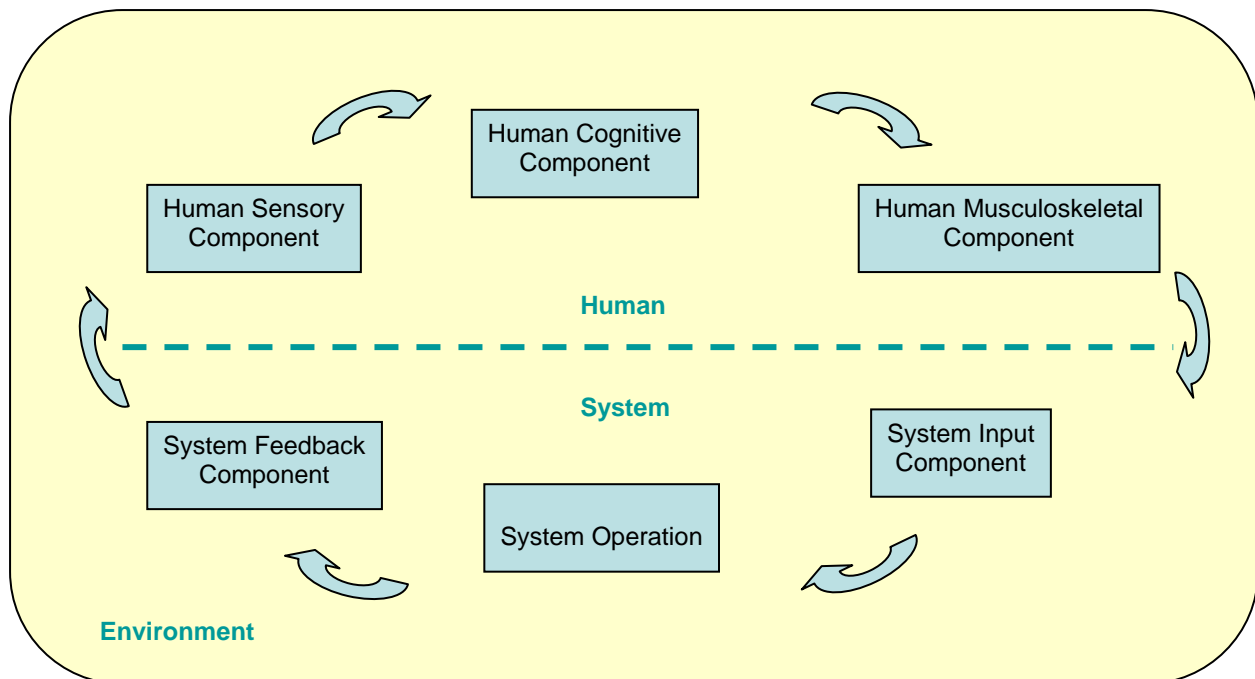
Figure 15: Model of the interaction of a human with a system.

A concept map was created based the Human System portion of the model (Figure 16). Appendix A shows the concepts that comprise this concept map. The concept map represents the human processes that take place when a worker interacts with any component of the organization. The concept map is intended to be all-inclusive of organizational/business components (including other workers) and not focus on automated or machine system components as the Human Factors Interaction Model portrays.
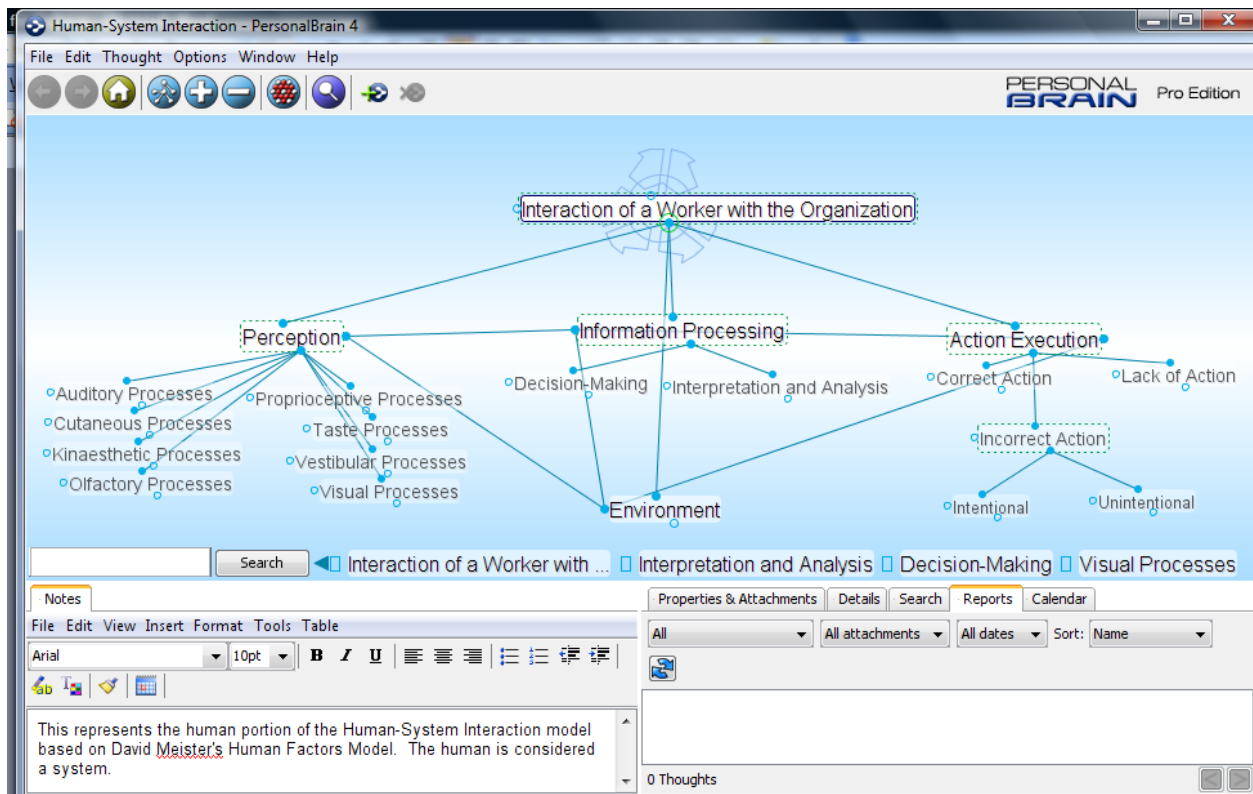
Figure 16: Interaction of a worker with the organization.

Performance Shaping Factors (PSFs) are used to describe factors that influence human performance. Miller and Swain (1987) divided PSFs into two distinct categories: internal and external. Internal PSFs are those that involve the attributes, skills and abilities of the individual. External PSFs relate to the nature of the physical environment or task situation, and are generally outside the control of the individual. These ideas generally accepted in the HFE/E field were used as a basis to create a concept map (Figure 17). The concept map was expanded based on the further classifications that the National Aeronautics and Space Administration use in their Root Cause Analysis tool (Figure 18 through Figure 21). The complete list of concepts that comprise this concept map; that is, the complete list of factors that influence that performance of a worker, is in Appendix B.
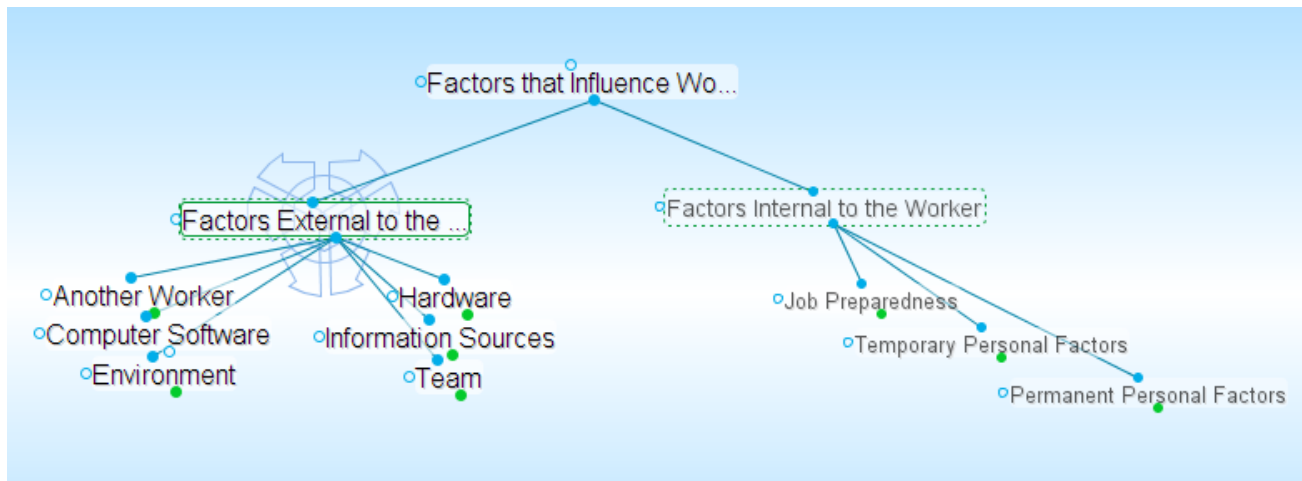
Figure 17: Factors that influence a worker's performance.
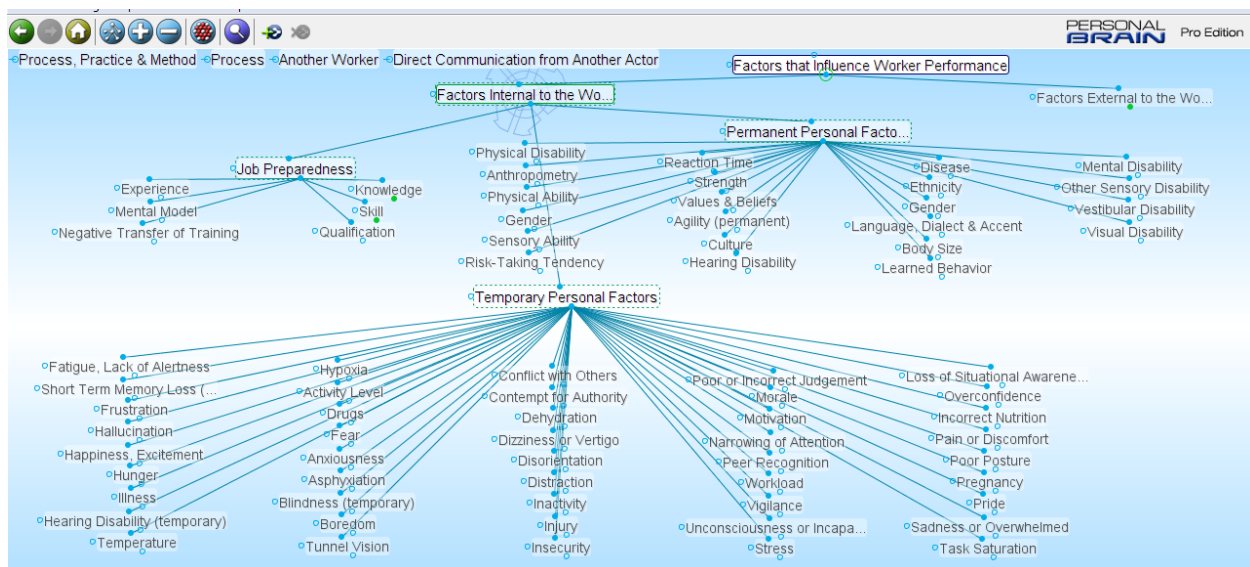
Figure 18: Factors internal to the worker that affect his/her own performance.
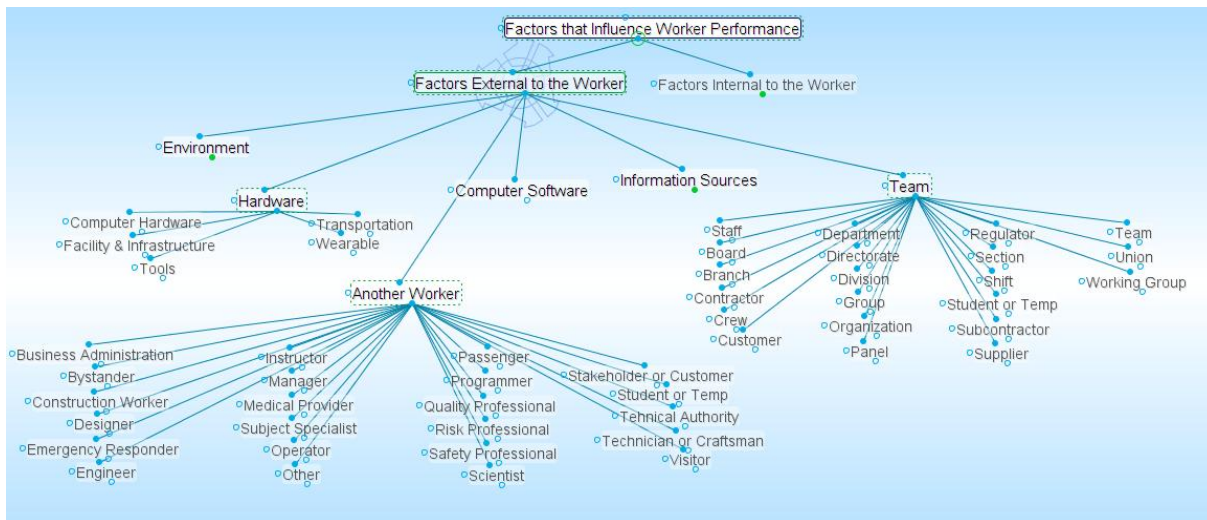
Figure 19: Factors external to the worker but which affect his/her performance (a).
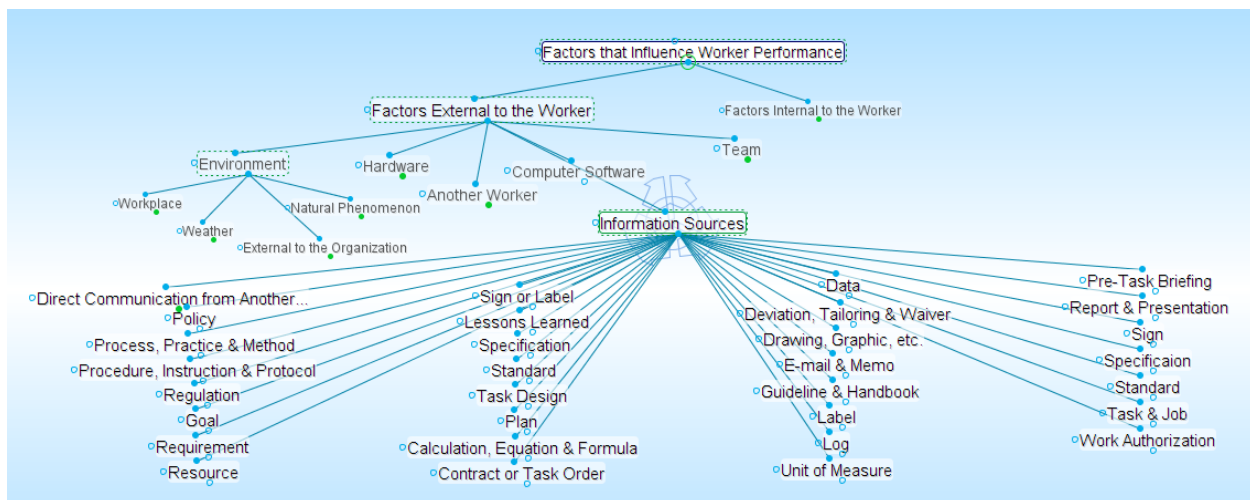
Figure 20: Factors external to the worker but which affect his/her performance (b).
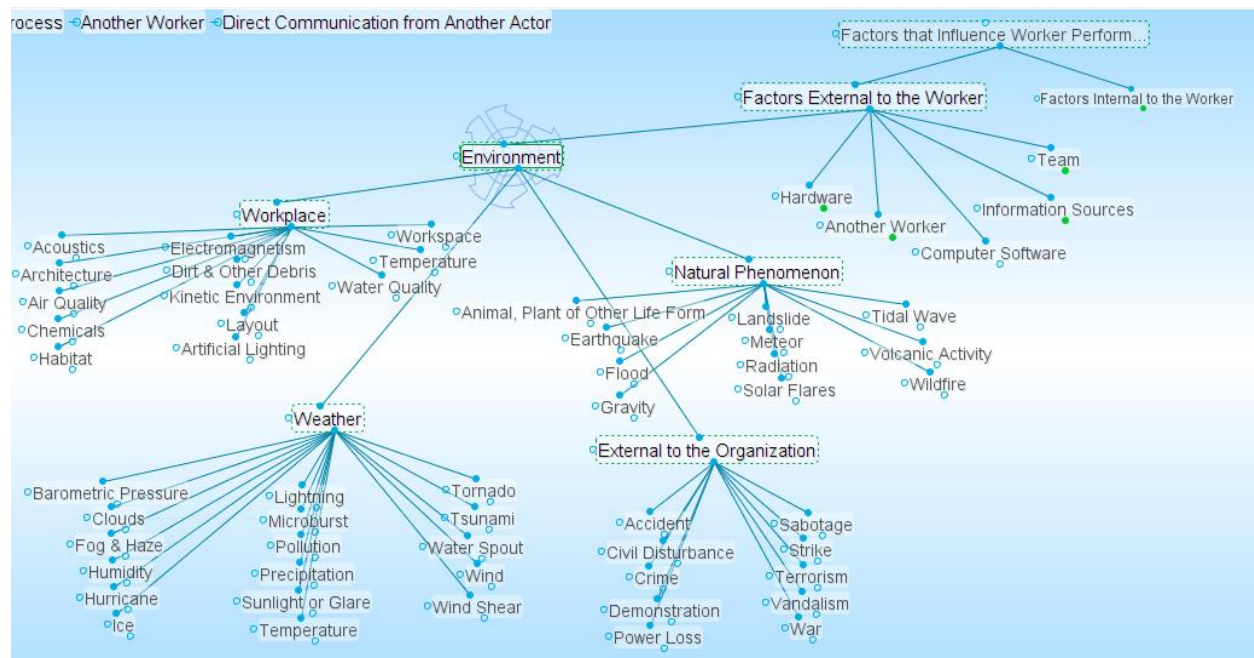
Figure 21: Factors external to the worker but which affect his/her performance (c).

The "Interaction of a worker with the organization" and the "Factors that influence worker performance" concept maps were merged (ref. Figure 22). Concepts were reviewed for consistency. Some concepts were deleted, some combined, some broken down, and some concept terms were modified, resulting in a total of 274 concepts (see Appendix C for the documentation of the changes made). The result was a concept map describing the high level factors that affect a person's interaction with the organization and, consequentially, the effect on performance. The complete list of concepts that comprise this third concept map is in Appendix D.

Figure 22 illustrates that, during a worker's interaction with the organization, that person perceives (receives through the senses) information from the organization, processes the

information perceived, and executes actions based on how that information was perceived (if it was perceived at all, if it was perceived adequately, etc.) and how that information was processed. Perception affects Information Processing which, in turn, affects Action Execution. Information Processing consists on, first, interpreting and/or analyzing the information perceived and then making a decision based on the results. All of these necessary processes for the worker's interaction with the organization are affected by influencing factors which can be internal (personal) to the worker or external to the worker. Actions performed by the worker may be correct, incorrect, or not performed (which is problematic if they were necessary or expected for his job), and the incorrect actions can be intentional or unintentional. The type of action is associated with the factors that affected the worker's performance, so an external influencing factor may be the cause of an unintentional incorrect action. An example would be a worker accidentally (unintentional action execution) shutting down a critical piece of equipment because the equipment's controls were incorrectly labeled (external factor).

Because of the large scale of this concept map (274 concepts - see Figure 23 for an illustration of the magnitude of the map) and because all concepts in a concept map are related to each another in some way, it was particularly important to be selective in identifying the most prominent and most useful cross-links. It is also important to understand that a concept map is never finished; so additional links may always be added if deemed necessary. The resulting map in Figure 23 was considered to provide the best synthesis of knowledge and enable the highest level of cognitive performance. The internal and external influencing factor concepts are still broken down into specific factors as shown in Figure 18 through Figure 21 (with the terminology modifications made when the first two maps were merged).
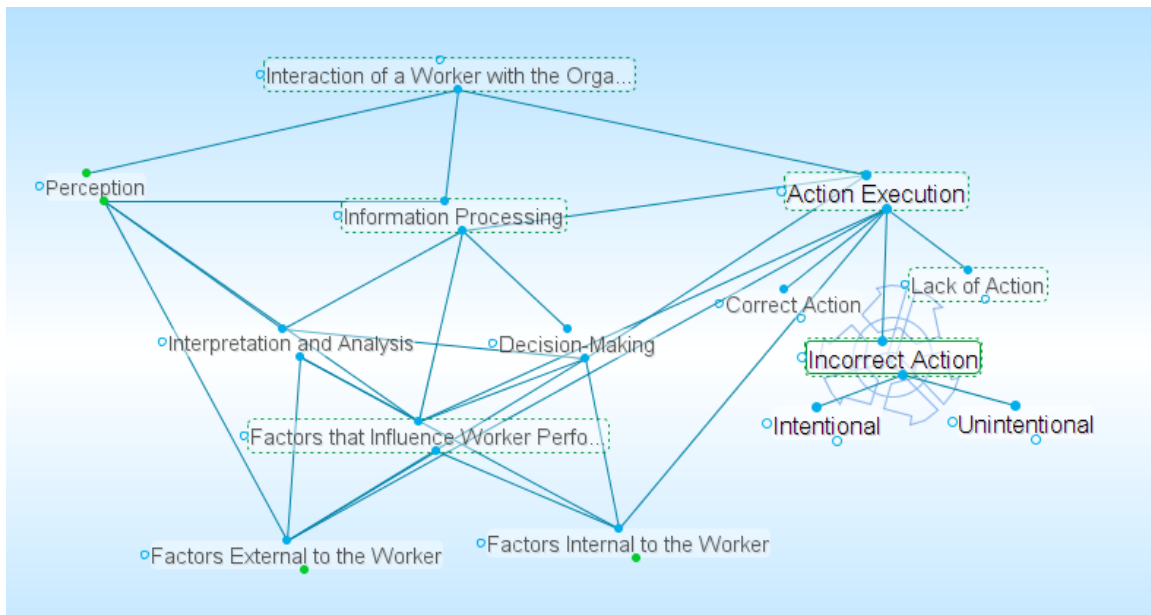
Figure 22: Merged "Interaction of a worker with the organization" and "Factors that influence worker performance" concept maps.
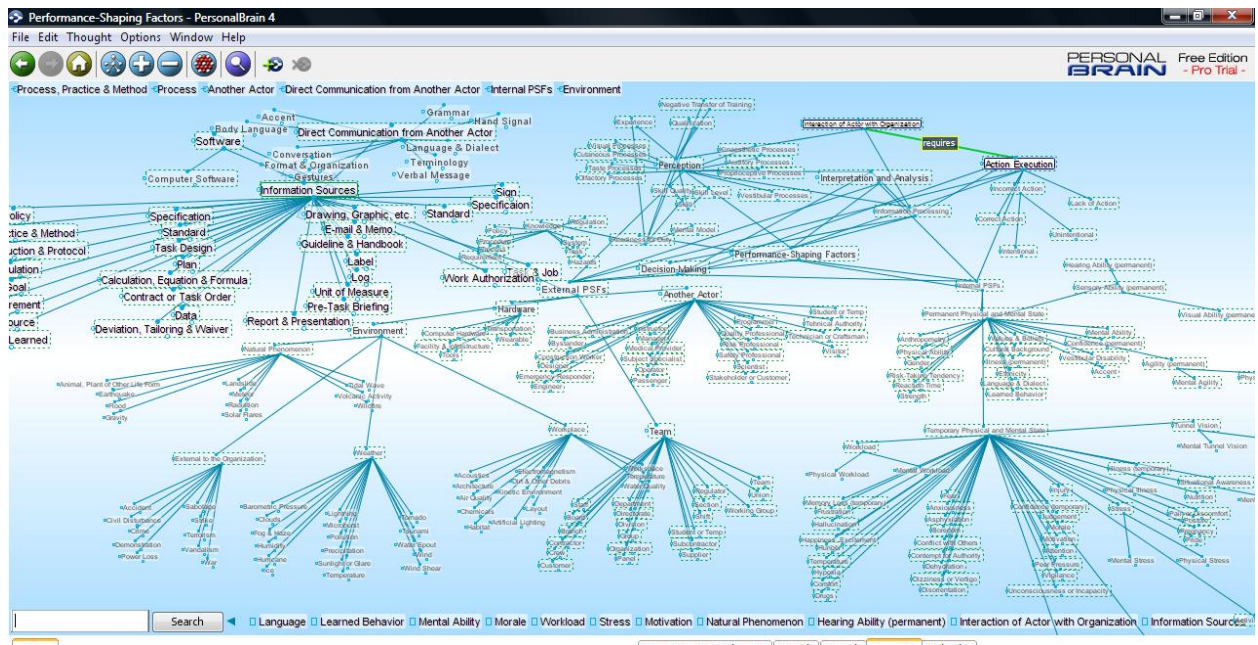
Figure 23: Fully extended merged maps.

The Ergonomics Abstracts is a focused, comprehensive, and international abstracting service spanning the world of HFE/E. It is a resource and reference tool developed as a result of the collaboration between the Ergonomics Information Analysis Center at the Taylor & Francis Ergonomics Resource Facility at The University of Birmingham, and Taylor & Francis. The Ergonomics Abstracts classification scheme was evaluated and relevant portions were used to create a HFE/E discipline taxonomy (Figure 24). Appendix E lists the complete HFE/E discipline taxonomy.
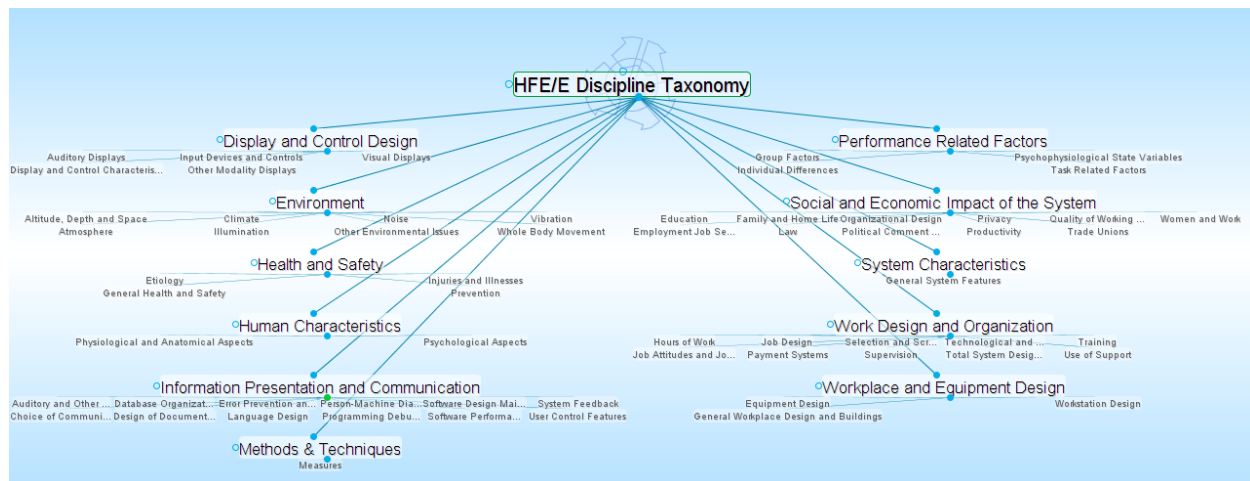
Figure 24: HFE/E Discipline Taxonomy, high levels only.

Finally, the third concept map and the taxonomy were merged into what became the first step of the generation of the HFE/E ontology. This combination resulted in 829 concepts that would need to be adequately mapped. The first task, as with the previous merge, consisted on ensuring terminology consistency among the concepts. All 829 terms were reviewed and minor modifications (documented in Appendix F) were made, most of which were typos fixed and are therefore not documented. The majority of the terminology modifications were made in the

previous merger. This time, it was very important to try to maintain the terminology from the Ergonomics Abstracts classification as these terms are accepted worldwide. Concept Mapping was used to make the connections among the components of the HFE/E ontology to-be. When creating links between concepts, the idea was to answer the question "How can the HFE/E discipline's specialty areas help in the interaction of an actor with the organization to produce the desired actions at the desired time?" The first set of cross-links between the two pieces of the ontology (the concept map and the taxonomy) was made at a high level as illustrated in Figure 25. This figure shows at a high level how the HFE/E discipline addresses the factors that influence a worker's performance within the organization and, therefore, how the integration of this knowledge into businesses would be beneficial to its overall performance. The conclusion of this concept map – taxonomy merge resulted in the HFE/E ontology.
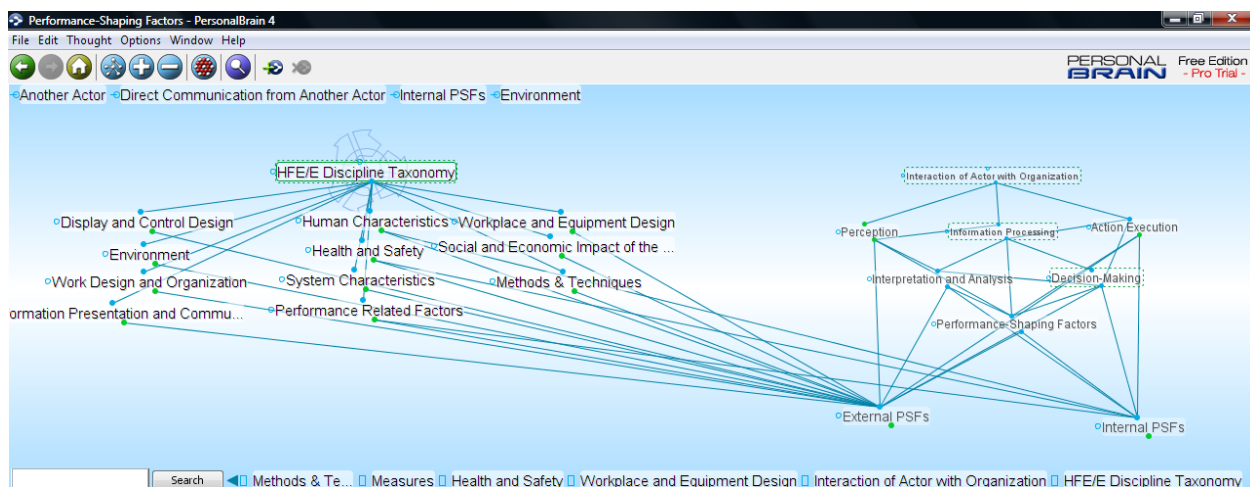
Figure 25: Phase 1 of the cross-links between the two HFE/E Ontology components.

Appendix G shows the spreadsheet that was used to plan the concept mapping to ensure a continued systematic approach from this point forward. Some HFE/E discipline taxonomy items were mapped at a higher level than others based on the researcher's assessment of the topic and usefulness of the level of detail necessary for the purpose of the HFE/E ontology. Items linked versus those not linked were documented in this spreadsheet along with concept pairs linked.

3.4.2 Software Tool Used

Several ontology editors were identified for potential use in this project, most of which were quickly eliminated for reasons such as being too early in their developmental stage, not being well known, or having been developed for a specific purpose not serving this project's needs. Following is a short review of the tools that were examined in greater detail, and a description of PersonalBrain, which was the tool chosen for this project.

Differential Ontology Editor (DOE)

DOE is a simple ontology editor that allows building ontologies according to the methodology proposed by Bruno Bachimont (2002). The specification process is divided into three steps:

1. A taxonomy of concepts and a taxonomy of relations are built, and the position of each item in the hierarchies is explicitly justified. For each item in the taxonomies, the user builds a definition following four principles from the Differential Semantics theory: the user has to explain why an item is similar but more specific than its parent (2 principles),

and why this item is similar but different from its siblings (2 other principles). The user may also add synonyms and encyclopedic definitions in several languages for all items.

2. The two taxonomies are considered from an extensional semantics point of view. This means that the user can expand the taxonomies by adding entities or by adding constraints to the domains of the relations.

3. The ontology can then be translated into a knowledge representation language, allowing its use in an appropriate ontology-based system and/or its import into another ontology editing tool for further specification.

DOE is not intended to be a full ontology development environment, so it does not actively support many activities that are involved traditionally in ontology construction such as advanced formal specification dealt with by tools like Protégé 2000. This did not present a problem for this project, as those advanced specifications would not be used. DOE is, on the other hand, a complement of others editors. It provides linguistics-inspired techniques which attach a lexical definition to the concepts and relations used, and justify their hierarchies from a theoretical, human-understandable point of view. This made the tool appealing at first. However, it was discarded for this project due to its lack of visual interface (see Figure 26) but primarily because of its developmental stage. The current version of DOE is a "(very) preliminary release" and "no guarantees are provided as to its utility or robustness!"
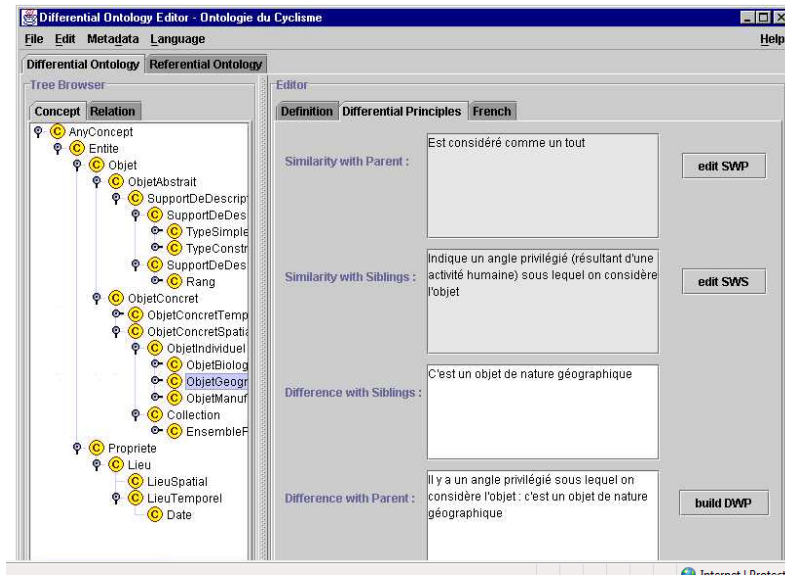
Figure 26: Differential Ontology Editor screenshot (DOE website. Used with permission.

The Ontolingua Server

This is a tool that enables collaborative ontology construction. Its source is the Knowledge Systems Laboratory at Stanford University in California. The server consists of a set of tools and services that support the process of achieving consensus on single, shared ontologies by groups located in different geographical locations, as well as individually owned ontologies. The tools enable wide access and provide users with the ability to publish, browse, create, evaluate, use, and edit ontologies stored on an ontology server by using the web. A strength of this tool is that it facilitates encoding ontologies in a reusable form which are kept in a library of modules. Existing ontologies from the ontology repositories can then quickly be assembled to create a new ontology for a specific application. As discussed earlier, this great capability is unfortunately not relevant to this project for the construction of the HFE/E ontology. However, it would be important for the HFE/E ontology to be able to be used by others to build new ontologies. The primary reason this tool was rejected is because it required a much greater level

of expertise in ontology building (not necessary for the purpose of this project) than that required for the tool that was finally selected.

Protégé

Protégé is a free, open source ontology editor and knowledge-base framework. It is based on Java, is extensible, and provides a plug-and-play environment that makes it a flexible base for rapid prototyping and application development. Protégé is supported by a strong community of developers and academic, government and corporate users (over 100,000 registered users), who are using it for knowledge solutions in diverse areas ranging from intelligence gathering to corporate modeling. Both of these applications were of interest in this project, and the fact that it has such a strong support and user base made it an attractive candidate tool. There are also many plug-ins and ontologies already built in Protégé, and the ontologies can be exported into a variety of formats including RDF(S), OWL, and XML Schema. These were, again, irrelevant bonuses of the tool for the purpose of this project. Protégé provides a set of tools to create domain models and knowledge-based applications with ontologies. It also supports the creation, visualization, and manipulation of ontologies in various representation formats, and can be customized to provide domain-friendly support for creating knowledge models and entering data.

Protégé's definition of ontology is: "An ontology describes the concepts and relationships that are important in a particular domain, providing a vocabulary for that domain as well as a computerized specification of the meaning of terms used in the vocabulary." Ontologies are further described as being central to applications such as scientific knowledge portals,

information management and integration systems, electronic commerce, and semantic web services. The Protégé platform supports two main ways of developing ontologies:

1. The Protégé-Frames editor enables users to build frame-based ontologies per the Open Knowledge Base Connectivity protocol. In this model, the ontology consists of: 1) a set of classes organized in a hierarchy representing a domain's most significant concepts, 2) a set of slots associated to the classes to describe properties and relationships, and 3) a set of instances of the classes. As explained earlier, the second and third components of these ontologies would be out of the scope of what is necessary for this project, making this editor excessive for the intended purpose.

2. The Protégé-OWL editor enables users to build ontologies for the Semantic Web specifically using the W3C's Web Ontology Language (OWL). Because OWL knowledge was required, this editor was also not considered further for this project.

    In conclusion, this tool was not selected mainly because its primary purpose seemed to be to serve users interested in building ontologies at a much lower specification level, and for software-related use. Usability and expert knowledge were likely problems for the beginner level necessary for this project.

PersonalBrain

    PersonalBrain was selected as the tool of choice for this project. It is one of TheBrain's two primary products. TheBrain Technologies is a leading provider of visual content management solutions that delivers information management solutions. TheBrain's products provide a context for smart information discovery and more informed decision-making. Some applications of TheBrain technology include customer care, project management, dynamic mind

mapping, IT management and helpdesks, impact assessment, competitive intelligence, marketing and sales support, and personal information management. PersonalBrain is a visual tool that provides great flexibility of the links created, allowing users to quickly create structures of information that reflect the way they think. As an associative information organization system, it allows any piece of information to be linked to any other piece within the ontology. Each item selected triggers related items, bringing relevant information together as it is needed. After going through the demo and some testing, the tool was selected as it possessed all of the characteristics desired for this project's tool.

3.5 Integration of HFE/E into Business Concept Map

The third goal of this project was to map the HFE/E discipline to business processes to enhance overall business performance. This was be done by mapping concepts from the HFE/E ontology to selected concepts from the business ontology. The method used to do this was concept mapping. Novak, first proposer of concept mapping, recommends building concept maps based on a particular question that needs to be answered or a situation that needs to be understood. The idea is to organize knowledge to answer that question or understand that situation in the form of a concept map. In this case, there was a question to be answered: "Which HFE/E ontology concepts would benefit which business ontology concepts to cause a positive effect on overall business performance?"

In the business context, HFE/E should use knowledge of human abilities and limitations to the design of the business as a system to achieve safe, efficient, comfortable and satisfying

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human use. For this, it is necessary to understand the interactions among the workforce (the human actors) and other elements of the business, and to apply HFE/E theory, principles, data and methods to the organization's design and operations in order to optimize the well-being of the workforce and the performance of the whole organization. HFE/E has three domains of specialization which must be appropriately integrated within organizations: physical ergonomics, cognitive ergonomics, and organizational ergonomics. To attempt this integration through ontology required the recognition of business concepts relevant to HFE/E. In addition, to make the integration universally applicable (useful for all types of businesses), the business ontology concepts had to also be common to all types of business ontologies.

As explained in a previous section, the review of existing business ontologies made possible the identification of some business concepts to which the HFE/E ontology are particularly relevant. There were additional key considerations for a comprehensive selection of business concepts and later a thorough and adequate mapping of HFE/E into business processes. Some of these important considerations were addressed by the differences in definitions of business concepts, some were just raised by those definitions, and others were briefly mentioned earlier in this document. The following paragraphs elaborate further to explain the reason for the selection of the business ontology concepts that finally constituted the business ontology used in this project.

When performing business activities, human actors should receive information and be able to apply knowledge according to their specific needs in a way that minimizes the disturbance of actors' core activities. Personalized, proactive and timely information and knowledge acquisition and application are important. Recent research projects like EDAMOK (Enabling Distributed and Autonomous Management of Knowledge) recognize the importance of

subjective, social and contextual factors in knowledge, and are promoting an approach to knowledge management that take these factors into account. However, solutions under development are not business process oriented and do not account for the dynamics of individual behavior at work. For example, human business actors perform multiple tasks and take on different roles. The possible combinations are associated with different behaviors and have different information needs. These needs depend on a variety of factors including individual features, task at hand and role played. Providing the required information, in the required manner, and at the required time entails considering not only actor, role and task-related features, but also the dynamics that govern task and role changing behavior (Zacarias et al, 2005). This not only applies to information requirements, but also to knowledge acquisition and application requirements. Information and knowledge needs of a human actor are determined by three main factors: (1) the individual person, (2) his or her position in the organizational structure, (3) the task at hand (Van Elst et al, 2001). The specific behavior and the information and knowledge needs of a human actor are defined by the combination of four factors: an *individual actor* performing a *task* under a given *role* at a certain *time*. Actors are typically modeled according to individual, task or role factors separately. In addition, humans typically alternate among several, independent tasks. When engaged in several activities, humans interrupt these activities and alternate among them according to myriad criteria such as task priorities, task resource's availability, hour preferences, completing shorter tasks first, etc. Moreover, humans possess multi-tasking capabilities, enabling human actors to handle several *action contexts* and participate in several *interaction contexts.* Also important is the fact that human actions combine human pre-defined and structured behavior (e.g. through the following of rules and procedures) with human ad-hoc behavior (Zacarias et al, 2005).

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By creating a HFE/E integration into business processes approach in which the HFE/E integration is accomplished through carefully selected business concepts, these important considerations can be addressed. This project's approach to HFE/E integration into businesses is believed to enable the response to the changing requirements and availability of resources in a business even when, as in most cases, human actors are described in business models as resources with a uniform and specialized behavior leading to representations of the human actor multiple behaviors as independent and unrelated units. Without these factors taken into consideration, there are serious limitations to the effectiveness of a HFE/E integration into organizations.

The business concepts selected for this project's business ontology were based on the analysis and comparison of the definitions from the business and enterprise ontologies reviewed, and based on the additional considerations particularly important to HFE/E as explained in the previous paragraphs and throughout this document.

Concept mapping was used to propose the HFE/E integration into organizations. The HFE/E ontology concepts were mapped to selected business ontology concepts. The resulting concept map shows how the HFE/E and business domains relate to each other to answer the question "Which HFE/E ontology concepts would benefit which business ontology concepts to cause a positive effect on overall business performance?" This final concept map (Figure 27) represents the creation of new knowledge as the cross-links (the links across the two ontology domains of HFE/E and business) correspond to creative leaps on the part of the knowledge producer.
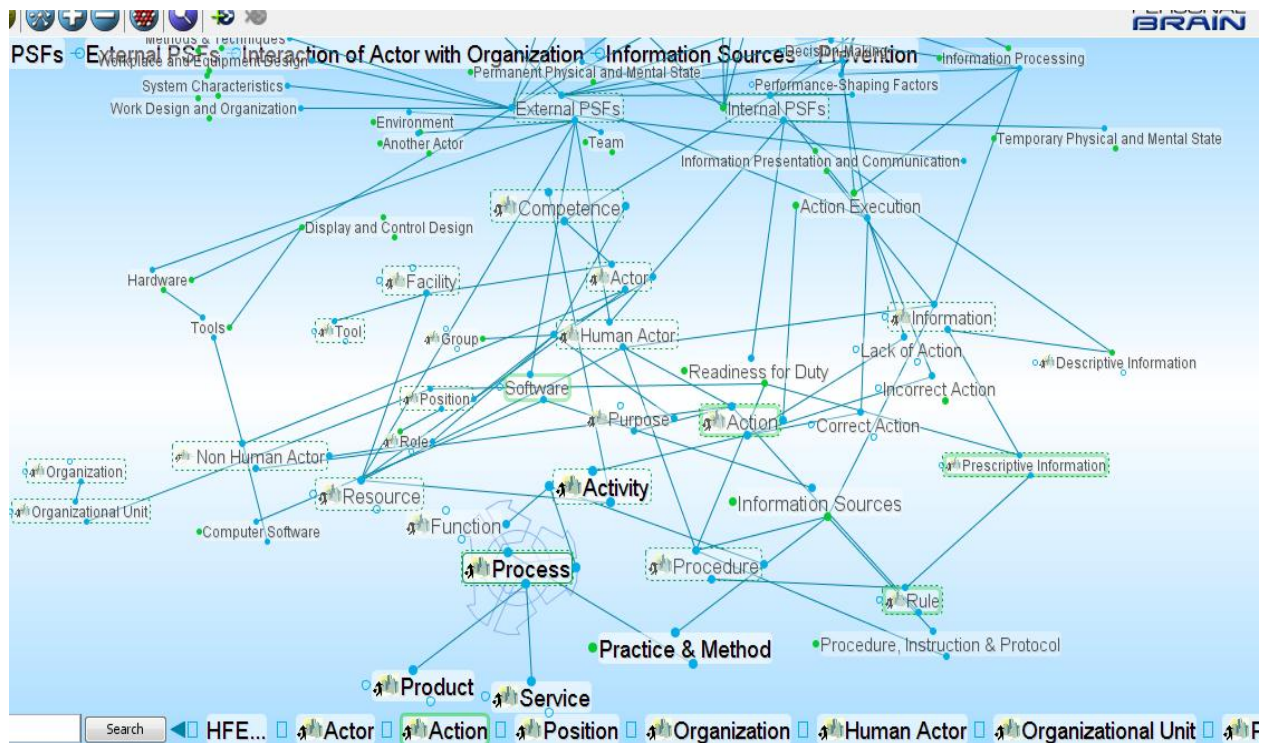
Figure 27: Portion of the HFE/E Integration into Business Concept Map.

The concepts that belong to the business ontology were differentiated by the use of an icon (notice that the concepts Activity, Process, Product and Service, for example, in Figure 27 have an icon that non-business concepts do not have). These concepts are the "plugs" that can be used to integrate this map into existing business ontologies to automatically illustrate a HFE/E integration into any organization.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

As discussed throughout the document, humans are critical system components affecting overall system performance, systems can only be optimized when all system components are addressed together as one system, and the human consideration needs to be integrated within and across all system elements. When a system is defined as an organization, this means that business performance can only be optimized if, among other requirements, the people in that organization are considered to be critical elements, if their capabilities and limitations are considered together with the remaining elements of the organization and, ultimately, if HSI is achieved throughout the components that comprise an organization. This requires a thorough HFE/E integration into businesses. To help organizations strive for optimal performance, the purpose of this research effort was to develop a method to integrate HFE/E knowledge into businesses, facilitating HSI in organizations.

4.1 Overview of Methodology

The methodology was divided into three major parts. The goal of the first part was to understand what the major components of a general business are, and what are common business processes and related activities. This was achieved by studying various business ontologies and creating a business ontology that would suit the purpose of this project. To reduce ontology development effort, and to make this project's outcome generalizable, existing ontology concepts

were used for this ontology's construction. Business ontology concepts were selected and adapted to fit their new purpose prior to inclusion in this ontology.

The second goal of this project was to understand how all of the HFE/E study areas relate to each other. Ontology was also used for this part of the project, in addition to Taxonomy and Concept Mapping. A concept map was created based on David Meister's model of how the human interacts with systems. A second concept map was created based on NASA's Root Cause Analysis Tool. The two concept maps were merged to generate a third concept map describing, very comprehensively, the factors that affect a worker's performance, and the effect of these factors on the worker's interaction with the organization in terms of performance. A taxonomy of the HFE/E discipline was built, which was combined with the third concept map to build a HFE/E ontology. Each merge included the review of all of the terms involved to ensure consistency.

The goal of the third part of the project was to integrate HFE/E into business components. This was achieved by mapping the HFE/E ontology to the business ontology created in the first part of the project. Concepts from the HFE/E ontology were mapped to selected concepts from the business ontology based answering the following question: "Which HFE/E ontology concepts would benefit which business ontology concepts to cause a positive effect on overall business performance?"

There are two major outcomes and several byproducts of this project. Byproducts are the first three concept maps that were generated. The first concept map is a visual representation and explanation of how a worker interacts with an organization. This concept map is generic and can be used to represent the interaction of any human with any system (from a toothbrush to an entire city system). The second concept map shows all of the factors that influence how people think and behave, and how they relate to each other. The third concept map brings together the two previous maps, clearly illustrating how each of the factors that influence people affects specific aspects of a person's performance. Some of the factors are organizational, and some are not, in which case it is still beneficial for an organization to take them into account for example when hiring, training, developing procedures, delivering information, deciding what to monitor, choosing whether to allocate a function to a person or to a machine, etc. Again, this concept map is generic and can be applied to study the factors that affect any person in his or her performance of any task (again, from brushing teeth to living in a city).

The two major outcomes are the HFE/E Ontology and the HFE/E Integration into Business Concept Map, both described next.

4.2.1 HFE/E Ontology

The development of the HFE/E ontology was guided to an important extent by existing work; namely David Meister's model describing the interaction of humans with systems,

NASA's Root Cause Analysis tool, and the Ergonomic Abstracts classification scheme. Possible uses for this ontology include accident investigation. NASA uses the Root Cause Analysis tool in part to systematically examine the factors that may have affected the performance of the people involved in an incident. This ontology enhances NASA's tool in two ways. First, it includes links to the human-system interaction model so that the factors can be directly correlated with an effect on decision-making or action execution-related problems, for example. An example of how this would be useful is the investigation of an incident in which there is evidence that a worker did not know that we should have been monitoring O2 levels. In this case, using this ontology the investigator would be able to eliminate all of the factors that are linked to problems with action execution or decision-making errors, and focus the remainder of the investigation in possible perception or interpretation-related factors. The second way in which this ontology enhances NASA's tool is by relating each performance influencing factor and performance effect to very specific HFE/E areas of study so that relevant information from the HFE/E discipline can be easily located. This is particularly beneficial to those unfamiliar with the field and its terminology. An example of the benefit of this additional resource would be finding that a worker did not take the correct steps to safe a system properly because he did not understand an error message on his computer. This ontology would let the investigator know that there is HFE/E information on related topics such as what are effective error messages, how to code information so that communication is effective, etc.

An additional possible use of this ontology would be in design. Say a wearable tool is being conceptualized, or the need for a new work procedure arises. This ontology would let the designer know what HFE/E study areas are related to wearable tools and work procedures respectively. In addition, this ontology would let the designer foresee possible future problems

caused by the wearable tool or the work procedure and what to, therefore, take into account to avoid them. For example, the HFE/E Integration into Business Concept Map shows how wearable tools relate to potential action execution problems and the reasons why (for example mobility issues). The work procedures have, in turn, links to interpretation errors and potential reasons for these errors include negative transfer of training (former related work experience that did not apply in this case).

This ontology can also be used by those in the HFE/E field who would like additional information in areas outside of their expertise, by those not familiar with the discipline to have a general idea of what the field covers, or by those studying HFE/E who want an overview of how what they are learning relates to everything else in the HFE/E world.

4.2.2 HFE/E Integration into Business Concept Map

The business ontology created for this project was based on concepts and terminology of existing business ontologies like the Enterprise Ontology, the Business Concepts Ontology, the Context-Based Enterprise Ontology, and the Core Business Process Analysis Ontology. The HFE/E Integration into Business Concept Map provides a pluggable framework based on those core business concepts, which are all required for supporting any kind of ontology-based business analysis in which the human actor (the workforce) is considered. The HFE/E Integration into Business Concept Map defines the appropriate "hooks" to enable it to be used as a business ontology extension. This way, it can serve as a HFE/E integration tool for any of the wide-range of ways in which organizations and their businesses processes may be analyzed through ontology.

This project puts forward a human actor centered perspective of the organization accounting for human multi-tasking and multi-role capabilities, and allowing dynamic, context-based, business process oriented and/or other approaches to examining the performance of organizations.

This concept map was developed to facilitate a thorough integration of the HFE/E discipline into organizations to enable the field to contribute to overall enterprise performance. The concept map achieves this goal by showing the links between each of the factors that influence how workers perform and the business concepts affected, as well as the HFE/E study areas that are related to those factors. For example, the concept map shows how having work procedures that can be misinterpreted by a worker can lead to poor service, therefore affecting the performance of an organizational unit. The concept map is comprehensive of the HFE/E field, the business concepts that workers affect, and the business concepts which influence people's performance, ensuring a complete overview of where HFE/E should be integrated in an organization, the specific HFE/E study areas that apply, and the reasons why (i.e., the effect on performance).

The ideal use of this tool is in the planning of a new organization; prior to structuring, purchasing, hiring, developing procedures, etc. This tool provides a complete source of information on what to take into consideration for an optimal workforce performance. For example, prior to generating policies, users would follow the concept map links to find what the related HFE/E study areas are, and could also follow links to see how policies in particular can affect the organization's performance and how to developed effective ones. Used this way, the tool would serve as a prevention method in the preparation against human-related low organizational performance. However, the tool can also be used to improve the performance of

already operating organizations. In the case in which a problem has been identified or is suspected, the tool could help pinpoint the cause (as in the root cause analysis, investigation use) or, if the cause is already known, the tool can recommend HFE/E study areas to implement to solve the problem. The following case study illustrates this use of the HFE/E Integration into Business Concept Map.

<u>4.3 Case Study</u>

"A Small Overseas Branch"

As a HFE/E consultant with an innovative approach to improve business performance and a friend (I'll call him Paul) running a business going through a rough time, I gave Paul a call to see if my research would be able to help. My plan was to first go with him over my business ontology and describe each of its concepts, explaining how they relate to each other. There are two purposes for this conversation: 1. to establish common terminology between the two of us, and 2. to limit the scope of the remainder of the discussion to areas that HFE/E can influence. By going through my business ontology, we would cover the "story" of how a business operates limiting the scope to what relates to HFE/E. I was then going to find out which of the business ontology concepts were associated with problems in his company by asking him what challenges he is having that relate to what we had just discussed about how a business runs.

Coincidentally, however, when I called Paul he was in a break from a corporate audit, so as soon as I told him what the purpose of my call was, he was able to quickly tell me what his two biggest problems are. So, although what I have just described would have been the approach I would take when first planning the integration of HFE/E into an existing organization (To

address the urgent problems first), in this case I was able to skip this part since what Paul considers to be his biggest problems were clear to him.

The following sentence summarizes his frustration with his situation as the president of the US branch of this company: "I could multiply my sales by two with no effort with the right tools" he said. When I asked what those tools were be he said "marketing, freedom, and… forecasting". Following is a brief background of the company and additional details on his two main problems, followed by an analysis performed using the HFE/E integration into business concept map.

Company's background:

- The company makes and sells high quality awnings. It was founded in 1970, is based in France, and has just under 700 permanent employees but hires another 300 to 400 during peak season. It is considered a very successful company in France. They make around 98 million Euros annually. Parts are made by the company in France.

- The US branch opened in 1997, has 5 employees, and made 3.2 million dollars last year (a substantial decrease from the previous year). The US branch only sells parts or assembles and sells the finished product. All parts are ordered from France

Next are the descriptions of what Paul considers his two main obstacles to higher performance.

Obstacle #1: Inability to forecast demand by quarter.

Related excerpts from the interview, in Paul's words: We are too slow in meeting demand. We are not organized as far as production and knowing what we have in stock. I check inventory when I place an order for a container,.. Within 3 months, so many things have changed… We

have problem predicting because you have to order things 3 months ahead. If I miss one part, I can't make an awning. I have to wait 3 more months.

Obstacle #2: CEO's personality.

Related excerpts from the interview, in Paul's words: The [company] owner is a self-made success. He started this company and became successful on his own… He wants to micromanage, to control everything, and doesn't listen to anybody's ideas… We're not motivated anymore. He is proud. He will not admit mistakes… He doesn't know the US market. I've been here for 10 years … we don't have any marketing at all. In Europe that works, but in the US, it's too much. It's a high end product. We have a good product but we don't sell. The market is right, but we don't market. Others have a really bad product compared to ours, but they market, so they sell even if they don't sell again to the same customers. You just don't try anything anymore, you know?

Analysis performed with the use of the HFE/E Integration into Business Concept Map

The business concepts affected by the two obstacles are identified as follows.

Obstacle #1: Inability to forecast demand by quarter (see Figure 28).

- Competence. Paul doesn't have the knowledge or information that he needs in order to place orders.

- Action. Paul performs unintended incorrect actions. He orders incorrect quantities per shipment.

- Process. The process of ordering a shipment is not done correctly as the quantity of parts requested is incorrect.

- Role. Paul performs multiple roles as the president (Paul's position) of this branch; but he is not qualified for all the roles.

- Service. Poor service because orders are late.

- Organizational unit. The US branch is performing poorly.
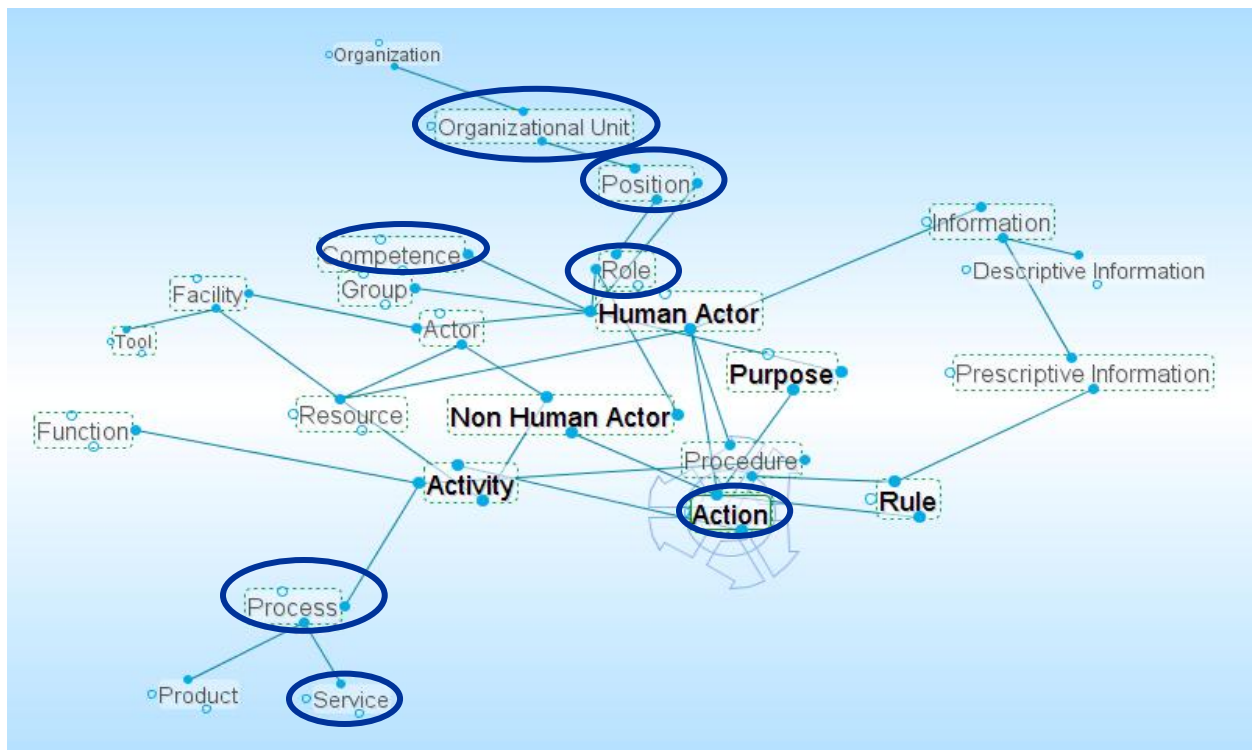
Figure 28: Business concepts affected by the inability to forecast demand.

Obstacle #2: CEO's personality (see Figure 29).

Action. Paul has lost desired to try to take initiative (no action). Paul is making intentional incorrect actions (not marketing even though he knows he needs it). The CEO is taking unintentional incorrect actions (e.g. not allowing marketing in the US).

Rule. Inadequate rule for the circumstances: no marketing allowed.

Human Actor. Paul's morale is low, he is stressed, and he has lost his motivation.

Competence. Paul feels competent to make decisions in the US which will enhance the organizational unit's performance, but his ability is not used. The CEO is not qualified to make some of the decisions he is making that affect the US branch but does not realize it.

Prescriptive information. Both the CEO and Paul are receiving prescriptive information from each other which is not enough for either to make the right decisions and perform adequate actions.

Organizational unit. The organizational unit is producing less than optimal results.

Position. The CEO has power over the president of the US branch regardless of competence for specific issues. Paul has responsibilities as the president of his branch but does not have the power to made the decisions he finds necessary.

Function. The marketing function is necessary but non existent due to an inadequate rule for this organizational unit.

Figure 29: Business concepts affected by the CEO's personality.

As explained earlier in this document, all concepts in a concept map are somehow related to each other. Therefore, the effects of a problem in one area have repercussions in other areas. For example, the lack of Paul's ability to forecast how many parts he will need in three months (competence) is the reason for his inability to correctly act (place his orders) which causes the inadequate process (delivery of parts) which makes the service (delivery to customer) suffer causing, in turn, poor organizational unit performance. All of these issues have a consequence on the human actor who feels badly about his performance. In this case, the human actor (Paul) in the position of president of the organizational unit feels responsible for the unit's poor performance although he is not empowered by a human actor in a superior position (the CEO) to make important decisions. Paul is well aware of his competence deficit but feels that his

concerns are not attended to by his superior. This is a link to the second obstacle: the CEO's personality. In this case study, the two problems Paul considers to be his obstacles are related to a common point: the CEO. The evaluation of these and more relationships between the business concepts are enabled by the portion of the HFE/E integration into business concept map illustrated in Figure 28 and in Figure 29, and aided by the business concepts definitions.

This discussion has lead to the conclusion that the source of the problems that were brought up by Paul is the CEO making decisions for which he is not fully qualified or informed, and for which Paul is responsible. Figure 30 shows the decision-making process of the CEO, some of the high-level factors affecting these decisions, and the link to the business performance. Important concepts in this figure are connected as described next. The CEO receives information (business concept identified in the figure by an icon) which he interprets and analyzes based on internal factors (such as his personality, including pride) and external factors (such as company goals). The resulting interpretation leads him to make decisions which result in actions. In this case the focus is on actions that are inadvertently incorrect, causing low performance in the organizational unit.
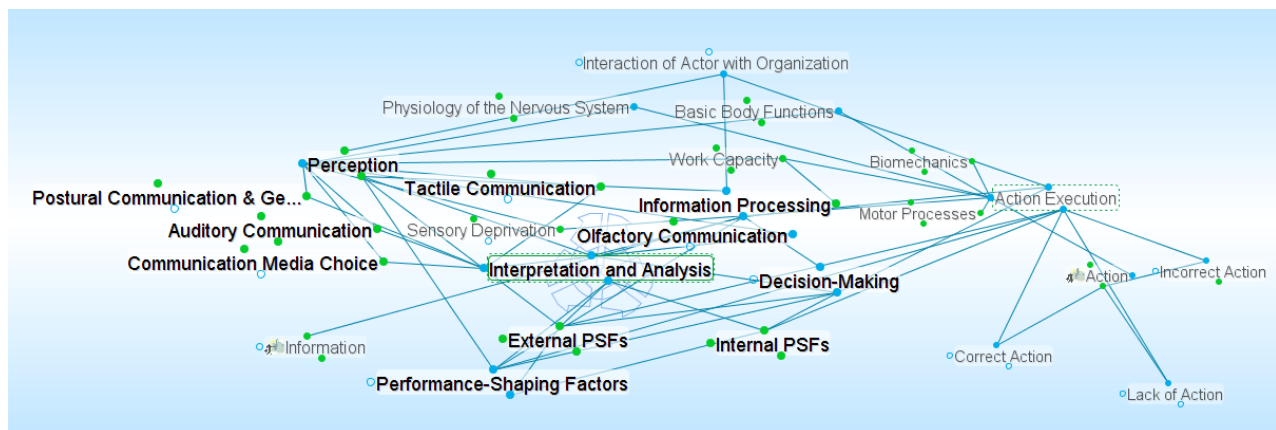

Figure 30: CEO's decision-making process.

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The remainder of the analysis will focus on helping the CEO process information adequately so that he can, in turn, perform correct actions for the improvement in performance of the US branch. See Figure 31 for the HFE/E integration into business concept map relevant to this portion of the analysis. The figure shows that the CEO processes the information he receives from the organization by first interpreting and analyzing it, then making a decision. The processing of the information he receives is affected by multiple factors.
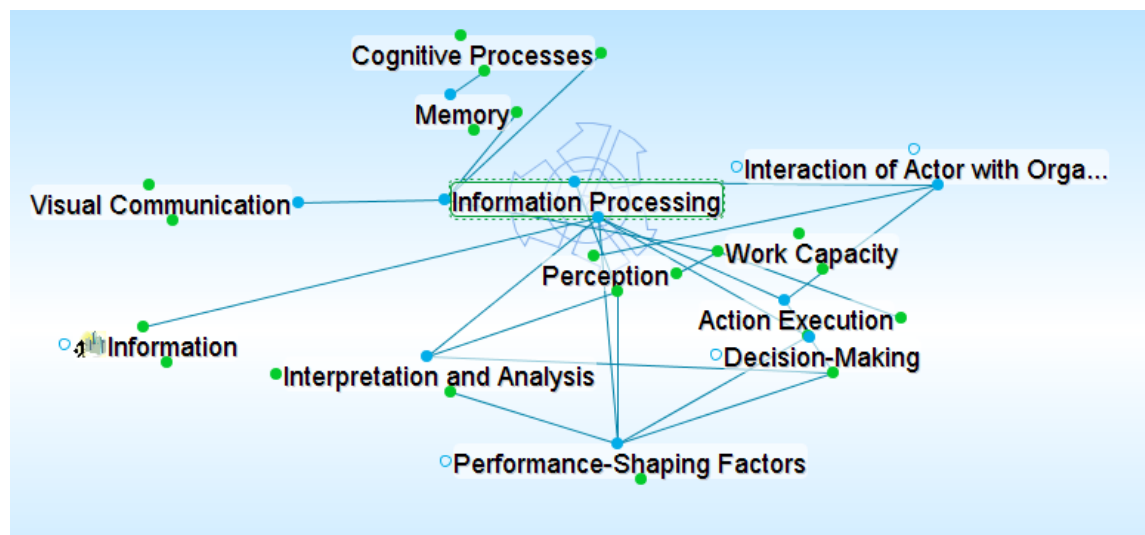
Figure 31: CEO's information processing.

We know that the problem in processing information is not due to lack of perception (i.e., the CEO's inability to read or to hear what is being given or told to him), or lack of understanding the language or terminology. The problem can be narrowed down to perhaps choice of communication media (information presentation and communication); the CEO's acquiring knowledge of the result of his own decisions; the feedback and feed-forward processes (task related factors of performance related factors); type of supervision the CEO uses (work

design and organization); organizational design, specifically management or information systems and communication; or the measures the CEO uses to make decisions (what is measured and how). Figure 32 shows the connection between the HFE/E study areas suggested as potential solutions to address the performance problem with the US branch and the CEO's decision making (which was earlier shown to be linked to the problems in the US).
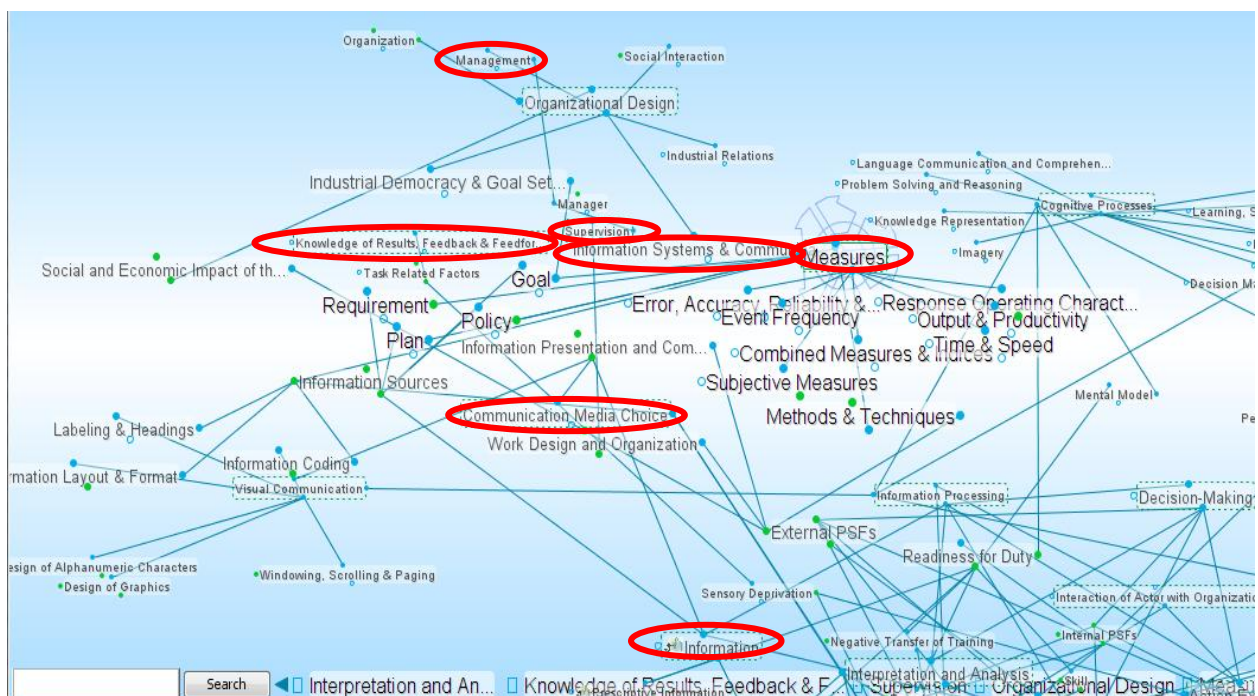
Figure 32: HFE/E specialty areas to consider to address performance problems in the US branch.

The recommendation at this point would be to investigate further the areas recommended so that the specific cause of the CEO's inadequate decisions can be pinpointed and addressed. This analysis has not been comprehensive but is an initial evaluation of the performance problems this company's branch is having that can be address by applying HFE/E knowledge. This evaluation has analyzed two problems identified by the person responsible for the

performance of an organization. It has identified a common origin for both problems, and

limited the potential causes of the poor performance suggesting possible sources of solutions.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

There is not one document that organizations can go to for recommendations on which of the myriad of HFE/E specialties should be applied to which of the multiple business components to achieve the HFE/E part of a comprehensive HSI to improve overall business performance. There is no methodology and structure available to help organizations integrate HFE/E into business processes. The purpose of this research effort was, therefore, to develop a methodology to integrate HFE/E knowledge into organizations to enhance business performance. This goal was accomplished by generating a concept map illustrating a comprehensive HFE/E integration into business concepts. This concept map was created combining two concept maps that were merged into a third concept map, which was in turn joined with a taxonomy to generate a HFE/E discipline ontology. A business ontology was built and mapped to the HFE/E ontology to complete the final step of the project's major product: the HFE/E integration into business concept map. A total of four concept maps, two ontologies and one taxonomy were built in this project, each described in the previous section. During this process, business concepts were studied in detail, as was the HFE/E discipline at a high level yet all-inclusive of the multiple discipline's study areas, and the relationship between the two domains.

The main outcome of this project, the HFE/E Integration into Business Concept Map, illustrates the complexity and broadness of the HFE/E discipline, and also the importance of applying the HFE/E knowledge presented for an effective, safe, comfortable and efficient business performance. Due to this complexity and broadness, it is clearly a vast task to integrate HFE/E into organizations. However, this project's outcome enables a structured and/or phased integration approach based on the needs or other criteria of the organization, as it breaks down

the information it provides in multiple ways. Business and HFE/E terminology used are consistent with the most commonly accepted terminology in both the business ontology and the HFE/E fields. As explained earlier, the HFE/E Integration into Business Concept Map provides a pluggable framework based on core business concepts that are required for supporting any type of ontology-based business analysis in which the workforce is included. The business ontology "hooks" provided enable the use of this concept map as an extension in order to take the HFE/E integration to a lower ontology level if desired, or to specific types of businesses.

5.1 Project Limitations and Planned Subsequent Research

This study is the preliminary research and lays the foundation for systems engineering software improvement through the incorporation of HFE/E into HSI and, as a result, the improvement of systems engineering. There are several ways in which this work will be taken steps further. One will require the transition to a different software tool or the addition of a couple of capabilities to PersonalBrain. The software tool selected for this project had two limitations that would have been beneficial to the user of the HFE/E integration into business concept map. One limitation was the inability to make the links show a direction, and the other was the inability to permanently display link descriptors. Most connections in the concept map can be read both ways; however, in some cases, there are specific relationships or propositions between concepts that are involved. In those cases it is very useful to be able to see what the link represents specifically, and in which direction the relationship applies. PersonalBrain did, however, have a capability that will greatly enhance the HFE/E integration into business concept map. This capability was not taken advantage of due to time constraints. It consists on including

attachments and on-line links to HFE/E resources. For example, hardware design guidelines will be easily accessed by this project outcome's user with the click of a mouse, as will be articles related to a specific subject (e.g. development of rules) or any published standards, specifications, research, etc. on the topic.

The HFE/E integration into business concept map will also be improved by adding definitions to every concept. The current map includes some definitions; but users not knowledgeable of the HFE/E field would benefit from additional descriptions. Taking this a step further, the concept map will be evolved into a knowledge base by defining individual instances of the classes and filling in specific slot value information and additional slot restrictions where appropriate. These steps will require the transition to an ontology editor and probably the involvement of an expert in ontology development.

Also, an improvement specifically for the HFE/E ontology will be its development into a formal ontology.

One important project limitation is the lack of validation of the work, which is planned as next steps of this research. The main project outcome will be evaluated in three ways. The first one will involve having HFE/E experts agree on the HFE/E ontology mapping to the business ontology (validate the links between the ontologies). The second evaluation will assess the usefulness of the main project outcome by potential users. In both of these cases, validation will rely upon Subject Matter Expert (SME) opinions. The third validation thrust will focus on the improvement of the bottom line and/or other benefits such as increased morale to the companies on which this tool is used. This third effort will focus on tangible benefits to a company resulting from integrating HFE/E into their organization.

5.1.1 Validation of the mapping of the 2 ontologies

HFE/E SMEs will consist of 10 individuals. Specific specialists will be selected based on expertise, years of experience, and accessibility. Knowledge elicitation will consist of group discussions and/or questionnaires. The choice of method will depend on the existing constraints, primarily access to experts and their available time.

A modified Delphi method will be used to validate the mapping of the HFE/E ontology to the business ontology. The Delphi method is a systematic, interactive forecasting method which relies on a panel of independent experts. Experts are carefully selected and answer questionnaires in two or more rounds after each of which a facilitator provides an anonymous summary of the experts' opinions from the previous round. The reasons the experts provided for their judgments are included; therefore, participants are able to revise their answers in light of the replies of other members of the group. The process is stopped after a pre-defined stop criterion (e.g. number of rounds, achievement of consensus, stability of results, etc.). The mean or median scores of the final rounds determine the results (Rowe and Wright, 1999).

The difference between this modified method, known as the mini-Delphi or the Estimate-Talk-Estimate (ETE), and the Delphi method is that the participants discuss their opinions at a meeting rather than through rounds of questionnaires. The advantage of using this method is the speed at which results are obtained, as participants are able to modify their final answers based on others' contributions right then. In the traditional Delphi method, the participants maintain anonymity even after the completion of the final report. This prevents participants from possibly dominating others through use of authority or personality; frees from personal biases; minimizes the "bandwagon" or "halo effect"; and encourages free expression of opinions, open critique and

admission of errors. To benefit from the advantages that anonymity provides, the meeting(s) will take place through teleconference, during which the participants' names will not be used.

The SMEs will be provided two items for preparation prior to the validation meeting:

1. A glossary of the business ontology concepts.

2. A table of the business concepts showing the HFE ontology concepts that were mapped to them.

During the validation meeting, participants will be asked to critique only the second item (the table of the business concepts showing the HFE ontology concepts that were mapped to them). The facilitator will go over each business concept and list the HFE study areas that are recommended for application to each. Participants will be asked to justify any disagreement with the recommendations considering that the purpose of such suggestions is for HFE/E to enhance the business' performance. After the reason for the disagreement is explained, the facilitator will first respond if clarification of the intent of the recommendation is necessary, and then invite all participants to voice further disagreement if it exists. Rounds of similar discussions will take place for each business concept with which the recommended HFE/E categories a participant does not agree. The objective of this process is to have all SMEs involved in this validation agree with the final version of the table. However, if unanimous consensus appears impossible, validation of the main outcome of the project will be considered successful when, for each HFE category listed in the table, 7 of the 10 SMEs participating agree that the HFE category applied to that particular business function will benefit the performance of the organization. Therefore, each round of validation discussions will be discontinued when this goal is achieved.

5.1.2 Validation of the usefulness of the main project outcome

SMEs will consist of 10 individuals from industry that would be potential users, with expertise in business performance or related areas, and with a higher education level. Specific specialists will be selected based on expertise, years of experience, and accessibility. Knowledge elicitation will consist of group discussions and/or questionnaires. The choice of method will depend on the existing constraints, primarily access to experts and their available time.

SMEs will be given a presentation in which the relevant areas of the HFE/E Integration into Business Concept Map building process are explained. The purpose of this presentation is to give the subjects a basic background in HFE/E and its influence on business performance. The SMEs will then be given the opportunity to ask any questions and participate in a general discussion to ensure they have a good understanding of the Concept Map's potential uses.

Next, the SMEs will be asked to complete a survey designed to judge the usefulness of the Concept Map. The survey will evaluate the Concept Map's usefulness for a variety of purposes including planning an overall HFE integration into an organization, planning a partial HFE integration into an organization, solving specific problems through HFE/E application, and identifying problems when the concerns are general and the specific causes are unknown.

5.1.3 Validation of the effect of using the HFE/E Integration into Business Concept Map on organizations' bottom lines

This third validation will focus on the improvement of the bottom line and/or other benefits such as increased morale to the companies on which this project's outcomes are used.

In other words, the focus is on tangible benefits to a company resulting from integrating HF/E into their organization using the method developed in this project. Data will be collected over the next 5 or more years as the method is used in different case studies. As these case studies are completed, a collection of data points comparing predetermined before and after measures will be evaluated to determine what would be anticipated benefits for organizations who use the HFE/E Integration into Business Concept Map. These measures will aim at quantifying improvements in the bottom line as well as quantifying progress in the specific areas responsible for those bottom line enhancements (such as reduction in turnover).

APPENDIX A: CONCEPTS IN THE "INTERACTION OF A WORKER WITH THE ORGANIZATION" CONCEPT MAP

<u>Interaction of a Worker with the Organization</u>
       Perception
              Auditory Processes
              Cutaneous Processes
              Kinaesthetic Processes
              Olfactory Processes
              Proprioceptive Processes
              Taste Processes
              Vestibular Processes
              Visual Processes
       Information Processing
              Decision-Making
              Interpretation and Analysis
       Action Execution
              Correct Action
              Incorrect Action
                     Intentional
                     Unintentional
              Lack of Action
       Environment

APPENDIX B: CONCEPTS IN THE "FACTORS THAT INFLUENCE WORKER PERFORMANCE" CONCEPT MAP

<u>Factors that Influence Worker Performance</u>
      Factors External to the Worker
           Another Worker
                Business Administration
                Bystander
                Construction Worker
                Designer
                Emergency Responder
                Engineer
                Instructor
                Manager
                Medical Provider
                Operator
                Other
                Passenger
                Programmer
                Quality Professional
                Risk Professional
                Safety Professional
                Scientist
                Stakeholder or Customer
                Student or Temp
                Subject Specialist
                Technician or Craftsman
                Tehnical Authority
                Visitor
           Computer Software
           Environment
                External to the Organization
                    Accident
                    Civil Disturbance
                    Crime
                    Demonstration
                    Power Loss
                    Sabotage
                    Strike
                    Terrorism
                    Vandalism
                    War
                Natural Phenomenon
                    Animal, Plant of Other Life Form
                    Earthquake
                    Flood
                    Gravity
                    Landslide

Meteor
                    Radiation
                    Solar Flares
                    Tidal Wave
                    Volcanic Activity
                    Wildfire
            Weather
                    Barometric Pressure
                    Clouds
                    Fog & Haze
                    Humidity
                    Hurricane
                    Ice
                    Lightning
                    Microburst
                    Pollution
                    Precipitation
                    Sunlight or Glare
                    Temperature
                    Tornado
                    Tsunami
                    Water Spout
                    Wind
                    Wind Shear
            Workplace
                    Acoustics
                    Air Quality
                    Architecture
                    Artificial Lighting
                    Chemicals
                    Dirt & Other Debris
                    Electromagnetism
                    Habitat
                    Kinetic Environment
                    Layout
                    Temperature
                    Water Quality
                    Workspace
    Hardware
            Computer Hardware
            Facility & Infrastructure
            Tools
            Transportation
            Wearable
    Information Sources

Calculation, Equation & Formula
Contract or Task Order
Data
Deviation, Tailoring & Waiver
Direct Communication from Another Actor
      Accent
      Body Language
      Conversation
      Format & Organization
      Gestures
      Grammar
      Hand Signal
      Language & Dialect
      Terminology
      Verbal Message
Drawing, Graphic, etc.
E-mail & Memo
Goal
Guideline & Handbook
Label
Lessons Learned
Log
Plan
Policy
Pre-Task Briefing
Procedure, Instruction & Protocol
Process, Practice & Method
Regulation
Report & Presentation
Requirement
Resource
Sign
Sign or Label
Specificaion
Specification
Standard
Standard
Task & Job
Task Design
Unit of Measure
Work Authorization

Team
Board
Branch
Contractor

Crew
Customer
Department
Directorate
Division
Group
Organization
Panel
Regulator
Section
Shift
Staff
Student or Temp
Subcontractor
Supplier
Team
Union
Working Group
Factors Internal to the Worker
Job Preparedness
Experience
Knowledge
Hazards
Policy
Procedure
Process
Regulation
Requirement
System
Task
Mental Model
Negative Transfer of Training
Qualification
Skill
Level
Quality
Permanent Personal Factors
Agility (permanent)
Anthropometry
Body Size
Cultural Background
Disease
Ethnicity
Gender
Gender

Hearing Disability
Language, Dialect & Accent
Learned Behavior
Mental Disability
Other Sensory Disability
Physical Ability
Physical Disability
Reaction Time
Risk-Taking Tendency
Sensory Ability
Strength
Values & Beliefs
Vestibular Disability
Visual Disability
Temporary Personal Factors
Activity Level
Anxiousness
Asphyxiation
Blindness (temporary)
Boredom
Conflict with Others
Confidence
Contempt for Authority
Dehydration
Disorientation
Distraction
Dizziness or Vertigo
Drugs
Fatigue, Lack of Alertness
Fear
Frustration
Hallucination
Happiness, Excitement
Hearing Disability (temporary)
Hunger
Hypoxia
Illness
Inactivity
Incorrect Nutrition
Injury
Insecurity
Loss of Situational Awareness
Morale
Motivation
Narrowing of Attention

Pain or Discomfort
Peer Recognition
Poor or Incorrect Judgement
Poor Posture
Pregnancy
Pride
Sadness or Overwhelmed
Short Term Memory Loss (temporary)
Stress
Task Saturation
Temperature
Tunnel Vision
Unconsciousness or Incapacity
Vigilance
Workload
Language
Learned Behavior
Mental Ability
Morale
Motivation
Stress
Workload

APPENDIX C: FIRST CONCEPT MAP MERGE TERMINOLOGY MODIFICATIONS

Terminology Changes

Old	New
Human-System Interaction	Interaction of a Worker with the Organization
Blindness (temporary)	Visual Ability (temporary)
Hearing Disability	Hearing Ability (permanent)
Incorrect Nutrition	Nutrition
Insecurity	Confidence (temporary)
Confidence	Confidence (permanent)
Language, Dialect & Accent	Language & Dialect
- added	Accent
Level	Skill Level
Quality	Skill Quality
Loss of Situational Awareness	Situational Awareness
Physical Disability	- Deleted (Physical Ability is there)
Mental Disability	Mental Ability
Other (under Another Actor ext PSF)	- Deleted
Poor Posture	Posture
Poor or Incorrect Judgement	Judgement
Other Sensory Disability	- Deleted (Sensory Ability is there)
Sensory Ability	Sensory Ability (permanent)
- Created	Visual Ability (permanent)
Visual Disability	- Deleted (Sensory Ability is there)
- Created	Sensory Ability (temporary)
- Created	Hearing Ability (temporary)
Sign or Label	Sign AND Label are both there
Short Term Memory Loss (temporary)	Memory Loss (temporary)
Inactivity	- Deleted (Activity Level is there)
Narrowing of Attention	Attention
Distraction	- Deleted (Attention is there)
Sadness or Overwhelmed	- Deleted (Happiness & Stressed are there)
- Created	Physical Workload
- Created	Mental Workload
- Created	Physical Stress
- Created	Mental Stress
- Created	Physical Activity
- Created	Mental Activity
Fatigue, Lack of Alertness	Fatigue
- Created	Physical Fatigue
- Created	Mental Fatigue
- Created	Physical Illness
- Created	Mental Illness
Overconfidence	- Deleted (Confidence is there)
- Created	Comfort
Peer Recognition	Peer Pressure
Task Saturation	- Deleted (Workload is there)

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- Created	Physical Tunnel Vision
- Created	Mental Tunnel Vision
Body Size	- Deleted (Anthropometry is there)
Disease	Illness (permanent)
Illness	Illness (temporary)
- Created	Physical Agility
- Created	Mental Agility
Morale (temporary)	Morale

APPENDIX D: CONCEPTS RESULTING FROM THE FIRST CONCEPT MAP MERGE

Merged "Interaction of a Worker with the Organization" and "Factors Influencing Worker Performance" concept maps

Interaction of a Worker with the Organization
    Action Execution
        Correct Action
        # Factors External to the Worker
        Factors Internal to the Worker
            Permanent Physical and Mental State
                Accent
                Agility (permanent)
                    Mental Agility
                    Physical Agility
                Anthropometry
                Confidence (permanent)
                Cultural Background
                Ethnicity
                Gender
                Illness (permanent)
                Language & Dialect
                Learned Behavior
                Mental Ability
                Physical Ability
                Reaction Time
                Risk-Taking Tendency
                Sensory Ability (permanent)
                    Hearing Ability (permanent)
                    Visual Ability (permanent)
                Strength
                Values & Beliefs
                Vestibular Disability
             Readiness for Duty
                Experience
                    # Perception
                Knowledge
                    Hazards
                    Policy
                    Procedure
                    Process
                    Regulation
                    Requirement
                    System
                    Task
                Mental Model
                Negative Transfer of Training

Perception
        Qualification
                # Perception
        Skill
                # Perception
                Skill Level
                Skill Quality
Temporary Physical and Mental State
        Activity Level
                Mental Activity
                Physical Activity
        Anxiousness
        Asphyxiation
        Attention
        Boredom
        Comfort
        Confidence (temporary)
        Conflict with Others
        Contempt for Authority
        Dehydration
        Disorientation
        Dizziness or Vertigo
        Drugs
        Fatigue
                Mental Fatigue
                Physical Fatigue
        Fear
        Frustration
        Hallucination
        Happiness, Excitement
        Hunger
        Hypoxia
        Illness (temporary)
                Mental Illness
                Physical Illness
        Injury
        Judgement
        Memory Loss (temporary)
        Morale
        Motivation
        Nutrition
        Pain or Discomfort
        Peer Pressure
        Posture
        Pregnancy

Pride
                        Sensory Ability (temporary)
                                Hearing Ability (temporary)
                                Visual Ability (temporary)
                        Situational Awareness
                        Stress
                                Mental Stress
                                Physical Stress
                        Temperature
                        Tunnel Vision
                                Mental Tunnel Vision
                                Physical Tunnel Vision
                        Unconsciousness or Incapacity
                        Vigilance
                        Workload
                                Mental Workload
                                Physical Workload
                # Factors that Influence Worker Performance
                Incorrect Action
                        Intentional
                        Unintentional
                Lack of Action
Information Processing
Perception
        Auditory Processes
        Cutaneous Processes
        Factors External to the Worker
                Another Actor
                        Business Administration
                        Bystander
                        Construction Worker
                        Designer
                        Emergency Responder
                        Engineer
                        Instructor
                        Manager
                        Medical Provider
                        Operator
                        Passenger
                        Programmer
                        Quality Professional
                        Risk Professional
                        Safety Professional
                        Scientist
                        Stakeholder or Customer

Student or Temp
Subject Specialist
Technician or Craftsman
Tehnical Authority
Visitor
Environment
External to the Organization
Accident
Civil Disturbance
Crime
Demonstration
Power Loss
Sabotage
Strike
Terrorism
Vandalism
War
Natural Phenomenon
Animal, Plant of Other Life Form
Earthquake
Flood
Gravity
Landslide
Meteor
Radiation
Solar Flares
Tidal Wave
Volcanic Activity
Wildfire
Weather
Barometric Pressure
Clouds
Fog & Haze
Humidity
Hurricane
Ice
Lightning
Microburst
Pollution
Precipitation
Sunlight or Glare
Temperature
Tornado
Tsunami
Water Spout

Wind
Wind Shear
Workplace
Acoustics
Air Quality
Architecture
Artificial Lighting
Chemicals
Dirt & Other Debris
Electromagnetism
Habitat
Kinetic Environment
Layout
Temperature
Water Quality
Workspace
Hardware
Computer Hardware
Facility & Infrastructure
Tools
Transportation
Wearable
Software
Computer Software
Information Sources
Calculation, Equation & Formula
Contract or Task Order
Data
Deviation, Tailoring & Waiver
Direct Communication from Another Actor
Accent
Body Language
Conversation
Format & Organization
Gestures
Grammar
Hand Signal
Language & Dialect
Terminology
Verbal Message
Drawing, Graphic, etc.
E-mail & Memo
Goal
Guideline & Handbook
Label

Lessons Learned
Log
Plan
Policy
Pre-Task Briefing
Procedure, Instruction & Protocol
Process, Practice & Method
Regulation
Report & Presentation
Requirement
Resource
Sign
Specificaion
Specification
Standard
Standard
Task & Job
Task Design
Unit of Measure
Work Authorization

Team
Board
Branch
Contractor
Crew
Customer
Department
Directorate
Division
Group
Organization
Panel
Regulator
Section
Shift
Staff
Student or Temp
Subcontractor
Supplier
Team
Union
Working Group

Factors that Influence Worker Performance
Factors External to the Worker
Factors Internal to the Worker

Information Processing
        # Action Execution
        Decision-Making
                # Action Execution
                # Factors External to the Worker
                # Factors Internal to the Worker
                # Factors that Influence Worker Performance
                # Interpretation and Analysis
        # Factors that Influence Worker Performance
        # Interpretation and Analysis
Interpretation and Analysis
        # Factors External to the Worker
        # Factors Internal to the Worker
        # Factors that Influence Worker Performance
Kinaesthetic Processes
Olfactory Processes
Proprioceptive Processes
Taste Processes
Vestibular Processes
Visual Processes
Language
Learned Behavior
Mental Ability
Motivation
Stress
Workload

APPENDIX E: HFE/E DISCIPLINE TAXONOMY

HUMAN CHARACTERISTICS

02 : PSYCHOLOGICAL ASPECTS [view]

    02-01 : Visual processes [view]

    02-02 : Auditory processes [view]

    02-03 : Cutaneous processes [view]

      02-03-01 : Touch and pressure sensitivity and perception [view]

      02-03-02 : Pain sensitivity and perception [view]

      02-03-03 : Temperature sensitivity and perception [view]

    02-04-00 : Taste and olfactory processes [view]

    02-05-00 : Kinaesthetic and proprioceptive processes [view]

    02-06-00 : Vestibular processes [view]

    02-08-00 : Time perception [view]

    02-09 : Cognitive processes [view]

      02-09-01 : Search [view]

      Memory

      02-09-02 : Sensory memory [view]

      02-09-03 : Short term memory and working memory [view]

      02-09-04 : Long term memory and semantic memory [view]

      02-09-05 : Knowledge representation [view]

      02-09-06 : Imagery [view]

      02-09-07 : Decision making and risk assessment [view]

      02-09-08 : Problem solving and reasoning [view]

      02-09-09 : Learning, skill development, knowledge acquisition and concept attainment [view]

      02-09-10 : Language communication and comprehension [view]

      02-09-11 : Reading [view]

    02-10 : Motor processes [view]

      02-10-01 : Movement organisation and motor programs [view]

      02-10-02 : Simple movements [view]

      02-10-03 : Complex movements [view]

      02-10-04 : Tracking movements [view]

      02-10-05 : Speech [view]

    02-11 : Human performance [view]

      02-11-01 : Reaction time and speed of performance [view]

      02-11-02 : Errors, accuracy and reliability [view]

      02-11-03 : Attention, time sharing and resource allocation [view]

      02-11-04 : Performance strategies [view]

      02-11-05 : Manual control [view]

      02-11-06 : Supervisory control [view]

    02-12-00 : Behavioural and social processes [view]

03 : PHYSIOLOGICAL AND ANATOMICAL ASPECTS [view]

    03-01 : Physiology of the nervous system [view]

      03-01-01 : Visual sensory system [view]

      03-01-02 : Auditory sensory system [view]

      03-01-03 : Other sensory systems [view]

      03-01-04 : Autonomic nervous system [view]

      03-01-05 : Brain function [view]

      03-01-06 : Effector system [view]

03-02 : Basic functions [view]
   03-02-01 : Cardiac processes [view]
   03-02-02 : Respiratory processes [view]
   03-02-03 : Metabolic processes [view]
   03-02-04 : Body temperature regulation [view]
   03-02-05 : Reproductive processes [view]
03-03 : Work capacity [view]
   03-03-01 : Static work capacity [view]
   03-03-02 : Dynamic work capacity [view]
03-04 : Biomechanics [view]
   03-04-01 : Static body measurements [view]
   03-04-02 : Dynamic body measurements [view]
   03-04-03 : Muscular strength and endurance [view]
   03-04-04 : Posture [view]
   03-04-05 : Simple movements [view]
   03-04-06 : Complex movements [view]

PERFORMANCE RELATED FACTORS

04 : GROUP FACTORS [view]
   04-01 : Age [view]
     04-01-01 : Children [view]
     04-01-02 : Young adults [view]
     04-01-03 : Middle aged adults [view]
     04-01-04 : Elderly adults [view]
  04-02 : Gender [view]
     04-02-01 : Male [view]
     04-02-02 : Female [view]
   04-03-00 : Culture and ethnic group [view]
   04-04-00 : Experience and practice [view]
   04-05-00 : Trained versus untrained [view]
   04-06-00 : Pregnancy [view]
   04-07-00 : Regional and geographical differences [view]
   04-08-00 : Status [view]
05 : INDIVIDUAL DIFFERENCES [view]
   05-01-00 : Intelligence [view]
   05-02 : Ability [view]
     05-02-01 : Mental ability [view]
     05-02-02 : Physical ability [view]
   05-03-00 : Personality and temperament [view]
   05-04-00 : Aptitude [view]
   05-05-00 : Achievement [view]
   05-06-00 : Attitude [view]
   05-07-00 : Physical fitness [view]
   05-08-00 : Laterality [view]
   05-09-00 : Cognitive style [view]
   05-10-00 : Users model, mental models and cognitive maps [view]
   05-11-00 : State of health [view]
06 : PSYCHOPHYSIOLOGICAL STATE VARIABLES [view]
   06-01 : Sleep [view]

16 : LANGUAGE DESIGN [view]
    16-01-00 : Programming language [view]
    16-02-00 : Natural language [view]
17 : DATABASE ORGANISATION AND DATA RETRIEVAL [view]
    17-01-00 : Relational database [view]
    17-02-00 : Hierarchical database [view]
    17-03-00 : Knowledge base and rule base [view]
    17-04-00 : Database management [view]
    17-05-00 : Knowledge engineering and acquisition [view]
18 : PROGRAMMING, DEBUGGING, EDITING AND PROGRAMMING AIDS [view]
19 : SOFTWARE PERFORMANCE AND EVALUATION [view]
20 : SOFTWARE DESIGN, MAINTENANCE AND RELIABILITY [view]
    20-01-00 : Intelligent interface design [view]
    20-02 : Interface management systems and tools [view]
      20-02-01 : Dialogue manager [view]

DISPLAY AND CONTROL DESIGN

21 : INPUT DEVICES AND CONTROLS [view]
    21-02 : Keyboards [view]
      21-02-01 : Two-handed keyboards [view]
      21-02-02 : One-handed keyboards [view]
      21-02-03 : Specialised keyboards [view]
      21-02-04 : Virtual keyboards [view]
    21-03-00 : Push buttons [view]
    21-04 : Switches [view]
      21-04-01 : Toggle switches [view]
      21-04-02 : Rotary switches [view]
      21-04-03 : Rocker switches [view]
    21-05-00 : Knobs [view]
    21-06-00 : Cranks [view]
    21-07 : Wheels [view]
      21-07-01 : Thumb wheels [view]
      21-07-02 : Hand wheels [view]
    21-08-00 : Levers [view]
    21-09-00 : Joysticks [view]
    21-10-00 : Pedals [view]
    21-11-00 : Push-pull handles [view]
    21-12-00 : Slide controls [view]
    21-13-00 : Bars [view]
    21-14-00 : Tracker ball and mouse [view]
    21-15 : Touch devices [view]
      21-15-01 : Touch panels [view]
      21-15-02 : Touch screens and displays [view]
      21-15-03 : Membrane keyboards [view]
      21-15-04 : Light pens [view]
      21-15-05 : Pointers [view]
    21-16-00 : Digitising and graphics tablets [view]
    21-17-00 : Multifunction controls [view]
    21-18 : Remote controls [view]
      21-18-01 : Remote manipulator controls [view]

WORKPLACE AND EQUIPMENT DESIGN

ENVIRONMENT

29-02 : Illumination quality [view]
    29-02-01 : Daylight contribution [view]
    29-02-02 : Colour characteristics [view]
    29-02-03 : Colour describing systems [view]
29-03 : Layout for illumination [view]
    29-03-01 : Visual comfort zone [view]
    29-03-02 : Disability glare [view]
    29-03-03 : Discomfort glare [view]
    29-03-04 : Veiling and specular reflections [view]
    29-03-05 : Glare control [view]
29-04-00 : Design of illuminants [view]
30 : NOISE [view]
    30-01-00 : Noise levels [view]
    30-02 : Noise quality [view]
      30-02-01 : Intermittent noise [view]
      30-02-02 : Continuous noise [view]
      30-02-03 : Music-while-you-work [view]
      30-02-04 : Noise frequency [view]
      30-02-05 : Infrasound [view]
      30-02-06 : Ultrasound [view]
      30-02-07 : Background speech [view]
    30-03 : Exposure to noise [view]
      30-03-01 : Auditory comfort [view]
      30-03-02 : Annoyance from noise [view]
      30-03-03 : Communication and masking in noise [view]
      30-03-04 : Temporary auditory threshold shift [view]
31 : VIBRATION [view]
    31-01-00 : Vibration levels [view]
    31-02-00 : Vibration quality [view]
32 : WHOLE BODY MOVEMENT [view]
    32-01-00 : Whole body velocity [view]
    32-02-00 : Whole body acceleration and deceleration [view]
    32-03-00 : Motion sickness [view]
33 : CLIMATE [view]
    33-01 : Temperature [view]
      33-01-01 : Low temperature [view]
      33-01-02 : High temperature [view]
    33-02-00 : Humidity [view]
    33-03-00 : Air speed [view]
    33-04-00 : Thermal stress [view]
    33-05-00 : Acclimatisation [view]
    33-06-00 : Dehydration [view]
    33-07-00 : Thermal comfort [view]
34 : ATMOSPHERE [view]
    34-01-00 : Particles and gases [view]
    34-02-00 : Static electricity [view]
    34-03-00 : Ionisation [view]
    34-04 : Radiation [view]
      34-04-01 : X-rays and gamma rays [view]

50-12-00 : Effects on the musculo-skeletal system [view]
51 : PREVENTION [view]
    51-01-00 : Health and safety propaganda [view]
    51-02-00 : Education, training and safety programmes [view]
    51-03-00 : Selection and screening for health and safety [view]
    51-04-00 : Supervision for health and safety [view]
    51-05-00 : Information and communication design for health and safety [view]
    51-06 : Display and control design for health and safety [view]
      51-06-01 : Emergency and warning devices [view]
    51-07-00 : Workplace and equipment design for health and safety [view]
    51-08-00 : Work design and organisation for health and safety [view]
    51-09 : Clothing [view]
      51-09-01 : Headgear [view]
      51-09-02 : Handgear [view]
      51-09-03 : Footgear [view]
      51-09-04 : Bodygear [view]
      51-09-05 : Clothing ensembles [view]
      51-09-06 : Materials for clothing [view]
    51-10 : Personal equipment [view]
      51-10-01 : Visual equipment [view]
      51-10-02 : Auditory equipment [view]
      51-10-03 : Thermal equipment [view]
      51-10-04 : Vibration equipment [view]
      51-10-05 : Respiratory equipment [view]
      51-10-06 : Body equipment [view]
      51-10-07 : Equipment for altitude and depth [view]
      51-10-08 : Equipment for space [view]
    51-11 : Emergency services [view]
      51-11-01 : Rescue [view]
      51-11-02 : First aid [view]
      51-11-03 : Evacuation procedures [view]
    51-12-00 : Rehabilitation [view]

SOCIAL AND ECONOMIC IMPACT OF THE SYSTEM

52 : TRADE UNIONS [view]
53 : EMPLOYMENT, JOB SECURITY AND JOB SHARING [view]
54 : PRODUCTIVITY [view]
    54-01-00 : Absenteeism [view]
    54-02-00 : Turnover [view]
    54-03-00 : Strikes [view]
    54-04-00 : Economic consequences [view]
55 : WOMEN AND WORK [view]
56 : ORGANISATIONAL DESIGN [view]
    56-01-00 : Management [view]
    56-02-00 : Industrial democracy and goal setting [view]
    56-03-00 : Social interaction [view]
    56-04-00 : Industrial relations [view]
    56-05-00 : Information systems and communication [view]
57 : EDUCATION [view]
58 : LAW [view]

METHODS AND TECHNIQUES

APPENDIX F: CONCEPT MAP AND TAXONOMY MERGE TERMINOLOGY MODIFICATIONS

Terminology Changes

Old	New
State of Health	Health
Basic Functions	Basic Body Functions
Choice of Communication Media	Communication Media Choice
Coding of Information	Information Coding
Comparison Between Dialogue Modes	Dialogue Mode Comparison
Individual Differences	Internal Factors - Individual Differences
Memory Loss (int PSF, temp state)	Memory
Vestibular Disability	Vestibular Ability
- Created	Age (perm int PSF)
Anxious	Anxiety
Artificial Lighting (Workplace Environm)	Illumination
PSFs	Factors that Influence Worker Performance
External PSFs	Factors External to the Worker
Internal PSFs	Factors Internal to the Worker
Readiness for Duty	Job Preparedness
Temporary Physical or Mental State	Temporary Personal Factors
Permanent Physical or Mental State	Permanent Personal Factors
Another Actor	Another Worker

APPENDIX G: BUSINESS ONTOLOGY TO HFE/E ONTOLOGY CROSS-LINK DOCUMENTATION

Linked?	HFE/E DISCIPLINE TAXONOMY	Linked to HSI - PSF CONCEPT MAP CONCEPT (part 1)	
N	**HUMAN CHARACTERISTICS**		
N	02 : PSYCHOLOGICAL ASPECTS [view]		
Y	02-01 : Visual processes [view]	Visual Ability (temp)	Visual ability (perm)
Y	02-02 : Auditory processes [view]	Hearing ability (temp)	Hearing ability (perm)
Y	02-03 : Cutaneous processes [view]	Sensory Ability (temp)	Sensory ability (perm)
Y	02-04 : Taste and olfactory processes [view]	Sensory Ability (temp)	Sensory ability (perm)
Y	02-05 : Kinaesthetic and proprioceptive processes [view]	Kinaesthetic Processes (from Perception)	Proprioceptive Processes (from Perception)
Y	02-06 : Vestibular processes [view]	Disorientation	Dizziness or Vertigo
N	02-08 : Time perception [view]		
Y	02-09 : Cognitive processes [view]	Information Processing	Readiness for Duty
Y	Memory	Information Processing	Mental Ability
Y	02-10 : Motor processes [view]	Action Execution	Physical Ability
Y	02-11 : Human performance [view]	Attention	Reaction Time
Y	02-12 : Behavioural and social processes [view]	Confidence	Contempt for Authority
N	03 : PHYSIOLOGICAL AND ANATOMICAL ASPECTS [view]		
Y	03-01 : Physiology of the nervous system [view]	Perception	Action Execution
Y	03-02 : Basic functions [view]	Perception	Action Execution
Y	03-03 : Work capacity [view]	Perception	Information Processing
Y	03-04 : Biomechanics [view]	Action Execution	
		Anthropometry	Strength
N	**PERFORMANCE RELATED FACTORS**		
N	04 : GROUP FACTORS [view]		
Y	04-01 : Age [view]	Age	
Y	04-02 : Gender [view]	Gender	
Y	04-03-00 : Culture and ethnic group [view]	Ethnicity	Cultural Background
Y	04-04-00 : Experience and practice [view]	Experience	Negative Transfer of Training
Y	04-05-00 : Trained versus untrained [view]	Readiness for Duty (Int PSF)	
Y	04-06-00 : Pregnancy [view]	Pregnancy	
Y	04-07-00 : Regional and geographical differences [view]	Values & Belied	Cultural Background
Y	04-08-00 : Status [view]	Confidence	Fear

Linked to HSI - PSF CONCEPT MAP CONCEPT (part 2)							
Visual Processes (from Perception)							
Auditory Processes (from Perception)							
Cutaneous Processes (from Perception)							
Olfactory Processes (from Perception)	Taste Processes (from Perception)						
Disorientation	Dizziness or Vertigo						
Vestibular Ability (perm)							
Permanent Physical & Mental State	Mental Model						
Reaction Time	Agility						
Agility							
Conflict with Others	Peer Pressure	Pride					
Action Execution	Attention	Boredom	Fatigue	Mental Ability	Physical Ability	Workload	
Physical Ability	Gender	Ethnicity	Comfort	Fatigue	Posture	Pain or	
Values & Beliefs							
Skill							
Language & Dialect	Learned Behavior						
				Learned	Risk-Taking		Values &
Peer Pressure	Pride	Stress	Behavior	Tendency		Beliefs	

Linked?	HFE/E DISCIPLINE TAXONOMY	Linked to HSI - PSF CONCEPT MAP CONCEPT (part 1)	
Y	05 : INDIVIDUAL DIFFERENCES [view]	Internal PSFs	
N	05-01-00 : Intelligence [view]		
N	05-02 : Ability [view]		
N	05-03-00 : Personality and temperament [view]		
N	05-04-00 : Aptitude [view]		
N	05-05-00 : Achievement [view]		
N	05-06-00 : Attitude [view]		
N	05-07-00 : Physical fitness [view]		
N	05-08-00 : Laterality [view]		
N	05-09-00 : Cognitive style [view]		
N	05-10-00 : Users model, mental models and cognitive maps [view]		
N	05-11-00 : State of health [view]		
N	06 : PSYCHOPHYSIOLOGICAL STATE VARIABLES [view]		
Y	06-01 : Sleep [view]	Fatigue	
Y	06-02 : Physiological rhythms [view]	Temporary Physical & Mental	
Y	06-03-00 : Arousal [view]	Happiness, Excitement	
Y	06-04 : Fatigue [view]	Fatigue	
Y	06-05-00 : Fear, anxiety, mood and emotion [view]	Fear	Anxiety
Y	06-06-00 : Nutrition and diet [view]	Nutrition	Hunger
Y	06-07 : Drugs [view]	Drugs	
N	07 : TASK RELATED FACTORS [view]		
Y	07-01-00 : Mental workload [view]	Mental Workload	
Y	07-02-00 : Physical workload [view]	Physical Workload	
Y	07-03-00 : Stress [view]	Stree	
Y	07-04-00 : Monotony and boredom [view]	Boredom	
Y	07-05-00 : Vigilance [view]	Vigilance	
N	07-06-00 : Knowledge of results, feedback and feedforward [view]		
Y	07-07-00 : Sensory deprivation [view]	Perception	Sensory ability (perm)
N	07-08-00 : Personal isolation [view]		
Y	07-09-00 : Task complexity [view]	Task & Job (Ext PSF)	Task Design (Ext PSF)
N	**INFORMATION PRESENTATION AND COMMUNICATION**		
Y	08 : VISUAL COMMUNICATION [view]	Information Processing	

Linked to HSI - PSF CONCEPT MAP CONCEPT (part 2)							
Happiness, Excitement	Morale						
Sensory ability (temp)							

Linked?	HFE/E DISCIPLINE TAXONOMY	Linked to HSI - PSF CONCEPT MAP CONCEPT (part 1)	
Y	08-01 : Design of alphanumeric characters [view]	Data	Calculation, Equation & Formula
Y	08-02 : Design of graphics [view]	Drawing, graphic, etc.	Sign
Y	08-03 : Coding of information [view]	Information Coding	
Y	08-04 : Information layout and format [view]	Information Sources	
Y	08-05 : Labelling and headings [view]	Information Sources	
Y	08-06 : Windowing, scrolling and paging [view]	Computer Software	
N	09 : AUDITORY AND OTHER COMMUNICATION MODALITIES [view]		
Y	09-01 : Auditory communication [view]	Perception	Direct Communication from
Y	09-02-00 : Tactile communication [view]	Perception	Direct Communication from
Y	09-03-00 : Postural communication and gestures [view]	Perception	Direct Communication from
Y	09-04-00 : Olfactory communication [view]	Perception	Interpretation and Analysis
Y	10 : CHOICE OF COMMUNICATION MEDIA [view]	Perception	Interpretation and Analysis
Y	11 : PERSON-MACHINE DIALOGUE MODE [view]	Hardware	Computer Software
N	11-01-00 : Comparison between dialogue modes [view]		
N	11-02-00 : Formal query dialogue [view]		
N	11-03-00 : Question & answer and computer inquiry [view]		
N	11-04 : Menus [view]		
N	11-05-00 : Form filling [view]		
N	11-06-00 : Commands and direct mode [view]		
N	11-07-00 : Restricted natural language [view]		
N	11-08-00 : Graphic dialogue [view]		
N	11-09-00 : Query-by-example [view]		
Y	12 : SYSTEM FEEDBACK [view]	Hardware	Computer Software
N	12-01-00 : Error messages [view]		
N	12-02-00 : Status messages [view]		
N	12-03-00 : Historical information [view]		
Y	13 : ERROR PREVENTION AND RECOVERY [view]	Hardware	Computer Software
N	13-01-00 : Identification of error [view]		
N	13-02-00 : Recovery from error [view]		
N	13-03-00 : Prevention of error [view]		
Y	14 : DESIGN OF DOCUMENTS AND PROCEDURES [view]	Information Sources	
N	14-01-00 : Instructions [view]		
N	14-02-00 : Manuals [view]		

Linked to HSI - PSF CONCEPT MAP CONCEPT (part 2)						
	Sign	Unit of Measure				
Interpretation and Analysis						
Interpretation and Analysis						
Interpretation and Analysis						
Information Sources						

Linked?	HFE/E DISCIPLINE TAXONOMY	Linked to HSI - PSF CONCEPT MAP CONCEPT (part 1)	
N	14-03 : Help documentation [view]		
N	14-04-00 : Work procedures [view]		
N	14-05-00 : Forms [view]		
N	14-06-00 : Program documentation [view]		
N	14-07-00 : Permit-to-work [view]		
Y	15 : USER CONTROL FEATURES [view]	Hardware	Computer Software
N	16 : LANGUAGE DESIGN [view]		
Y	16-01-00 : Programming language [view]	Computer Software	
Y	16-02-00 : Natural language [view]	Information Sources	
Y	17 : DATABASE ORGANISATION AND DATA RETRIEVAL [view]	Data	
N	17-01-00 : Relational database [view]		
N	17-02-00 : Hierarchical database [view]		
N	17-03-00 : Knowledge base and rule base [view]		
N	17-04-00 : Database management [view]		
N	17-05-00 : Knowledge engineering and acquisition [view]		
Y	18 : PROGRAMMING, DEBUGGING, EDITING AND PROGRAMMING AIDS [view]	Computer Software	
Y	19 : SOFTWARE PERFORMANCE AND EVALUATION [view]	Computer Software	
Y	20 : SOFTWARE DESIGN, MAINTENANCE AND RELIABILITY [view]	Computer Software	
N	20-01-00 : Intelligent interface design [view]		
N	20-02 : Interface management systems and tools [view]		
Y	**DISPLAY AND CONTROL DESIGN**	Computer Hardware	Tools
N	21 : INPUT DEVICES AND CONTROLS [view]		
N	21-02 : Keyboards [view]		
N	21-03-00 : Push buttons [view]		
N	21-04 : Switches [view]		
N	21-05-00 : Knobs [view]		
N	21-06-00 : Cranks [view]		
N	21-07 : Wheels [view]		
N	21-08-00 : Levers [view]		
N	21-09-00 : Joysticks [view]		
N	21-10-00 : Pedals [view]		
N	21-11-00 : Push-pull handles [view]		

Linked to HSI - PSF CONCEPT MAP CONCEPT (part 2)						
Wearable Hardware						

Linked?	HFE/E DISCIPLINE TAXONOMY	Linked to HSI - PSF CONCEPT MAP CONCEPT (part 1)	
N	21-12-00 : Slide controls [view]		
N	21-13-00 : Bars [view]		
N	21-14-00 : Tracker ball and mouse [view]		
N	21-15 : Touch devices [view]		
N	21-16-00 : Digitising and graphics tablets [view]		
N	21-17-00 : Multifunction controls [view]		
N	21-18 : Remote controls [view]		
N	21-19-00 : Teach controls [view]		
N	21-20 : Image processing devices [view]		
N	21-21-00 : Voice input devices [view]		
N	21-22-00 : Tactile input devices [view]		
N	21-23-00 : Triggers [view]		
N	22 : VISUAL DISPLAYS [view]		
N	22-01 : Optical aids [view]		
N	22-03-00 : Dials, meters and gauges [view]		
N	22-04 : Luminous displays [view]		
N	22-05 : Headup and projected displays [view]		
N	22-06-00 : Multifunction displays [view]		
N	22-07-00 : Conspicuity aids [view]		
N	22-08-00 : Signs [view]		
N	22-09 : Status displays and boards [view]		
N	22-10-00 : Remote manipulator displays [view]		
N	22-11-00 : Printing devices [view]		
N	23 : AUDITORY DISPLAYS [view]		
N	23-01-00 : Auditory aids [view]		
N	23-02-00 : Voice output and speech synthesis [view]		
N	24 : OTHER MODALITY DISPLAYS [view]		
N	24-01 : Tactile displays [view]		
N	24-02-00 : Mixed modality displays [view]		
N	24-03-00 : Olfactory displays [view]		
N	25 : DISPLAY AND CONTROL CHARACTERISTICS [view]		
N	25-01 : Display dynamics [view]		
N	25-02 : Display quality [view]		
N	25-03-00 : Display layout [view]		
N	25-04-00 : Control dynamics [view]		

Linked?	HFE/E DISCIPLINE TAXONOMY	Linked to HSI - PSF CONCEPT MAP CONCEPT (part 1)	
N	25-05-00 : Control layout [view]		
N	25-06 : Display-control relationships [view]		
N	25-07-00 : Paper versus screen [view]		
N	**WORKPLACE AND EQUIPMENT DESIGN**		
Y	26 : GENERAL WORKPLACE DESIGN AND BUILDINGS [view]	Facility and Infrastructure (Hardware)	
N	26-01-00 : Large scale layout and plant layout [view]		
N	26-02-00 : Floors [view]		
N	26-03-00 : Windows [view]		
N	26-04 : Movement through working areas [view]		
Y	27 : WORKSTATION DESIGN [view]	Facility and Infrastructure (Hardware)	
N	27-01 : Workstation dimensions [view]		
N	27-02 : Workstation layout and arrangement [view]		
N	28 : EQUIPMENT DESIGN [view]		
Y	28-01-00 : Machine tools [view]	Tools	
Y	28-02 : Hand tools [view]	Tools	
Y	28-03-00 : Consumer product design [view]	Hardware	
Y	28-04 : Furniture [view]	Facility and Infrastructure (Hardware)	
Y	28-05 : Vehicles [view]	Transportation	
Y	28-06 : Supplementary equipment [view]	Hardware	
	ENVIRONMENT		
Y	29 : ILLUMINATION [view]	Illumination	
N	29-01 : Illumination levels [view]		
N	29-02 : Illumination quality [view]		
N	29-03 : Layout for illumination [view]		
N	29-04-00 : Design of illuminants [view]		
Y	30 : NOISE [view]	Acoustics	
N	30-01-00 : Noise levels [view]		
N	30-02 : Noise quality [view]		
N	30-03 : Exposure to noise [view]		
Y	31 : VIBRATION [view]	Workplace	
N	31-01-00 : Vibration levels [view]		
N	31-02-00 : Vibration quality [view]		
Y	32 : WHOLE BODY MOVEMENT [view]	Kinetic Environment	

Linked?	HFE/E DISCIPLINE TAXONOMY	Linked to HSI - PSF CONCEPT MAP CONCEPT (part 1)	
N	32-01-00 : Whole body velocity [view]		
N	32-02-00 : Whole body acceleration and deceleration [view]		
N	32-03-00 : Motion sickness [view]		
Y	33 : CLIMATE [view]	Workplace	
Y	33-01 : Temperature [view]	Temperature (Workplace)	
N	33-02-00 : Humidity [view]	Humidity (Workplace)	
N	33-03-00 : Air speed [view]		
T	33-04-00 : Thermal stress [view]	Physical Stress (temp int PSF)	
N	33-05-00 : Acclimatisation [view]		
Y	33-06-00 : Dehydration [view]	Dehydration (temp int PSF)	
Y	33-07-00 : Thermal comfort [view]	Temperature (temp int PSF)	
Y	34 : ATMOSPHERE [view]	Workplace (Environment)	
N	34-01-00 : Particles and gases [view]		
N	34-02-00 : Static electricity [view]		
N	34-03-00 : Ionisation [view]		
N	34-04 : Radiation [view]		
Y	35 : ALTITUDE, DEPTH AND SPACE [view]	Temporary Physical & Mental State	
N	35-01-00 : Barometric pressure [view]		
Y	35-02-00 : Hypoxia [view]	Hypoxia	
N	35-03-00 : Hyperoxia [view]		
N	35-04-00 : Weightlessness [view]		
Y	35-05-00 : Disorientation [view]	Disorientation	
Y	36 : OTHER ENVIRONMENTAL ISSUES [view]	Environment	
N	36-02-00 : Combined environments [view]		
	SYSTEM CHARACTERISTICS		
Y	37 : GENERAL SYSTEM FEATURES [view]	Hardware	Computer Software
N	37-01-00 : System friendliness, usability and acceptability [view]		
N	37-02-00 : System adaptability and flexibility [view]		
N	37-03-00 : System facilities [view]		
N	37-04-00 : System dynamics [view]		
N	37-05-00 : System response time [view]		
N	37-06-00 : System availability [view]		
N	37-07-00 : System reliability [view]		

Linked?	HFE/E DISCIPLINE TAXONOMY	Linked to HSI - PSF CONCEPT MAP CONCEPT (part 1)	
N	37-08-00 : System security and integrity [view]		
N	37-09-00 : System transparency [view]		
N	37-10-00 : System performance and evaluation [view]		
N	37-11-00 : System design and interface engineering [view]		
N	37-12-00 : Aesthetics [view]		
N	37-13-00 : System consistency [view]		
	WORK DESIGN AND ORGANIZATION		
N	38 : TOTAL SYSTEM DESIGN AND EVALUATION [view]		
Y	38-01-00 : Allocation of function [view]	Task & Job (Ext PSF)	Task Design (Ext PSF)
N	38-02 : Design and development process [view]		
N	39 : HOURS OF WORK [view]		
Y	39-01-00 : Shift work [view]	Process, Practice, Method	Policy
Y	39-02-00 : Rest pauses and work duration [view]	Task & Job (Ext PSF)	Task Design (Ext PSF)
Y	40 : JOB ATTITUDES AND JOB SATISFACTION [view]	Temporary Physical & Mental State	
Y	41 : JOB DESIGN [view]	Task & Job (Ext PSF)	Task Design (Ext PSF)
N	41-01 : Job restructuring [view]		
N	41-02 : Work organisation and sociotechnical systems [view]		
N	41-03 : Job characteristics [view]		
N	41-04 : Work context factors [view]		
Y	42 : PAYMENT SYSTEMS [view]	Policy	
Y	43 : SELECTION AND SCREENING [view]	Readiness for Duty (Int PSF)	
Y	44 : TRAINING [view]	Readiness for Duty (Int PSF)	Requirement
Y	45 : SUPERVISION [view]	Manager	
Y	46 : USE OF SUPPORT [view]	Information Sources	
Y	46-01-00 : Use of instructions [view]	Guideline and Handbook	Procedure, Instruction & Protocol
Y	46-02-00 : Use of manuals [view]	Guideline and Handbook	
Y	46-03-00 : Use of within system documentation [view]	Information Sources	
Y	46-04-00 : Use of human support [view]	Direct Communication from Another Actor	Team
Y	46-05-00 : Use of work procedures [view]	Work Authorization	Procedure, Instruction & Protocol
Y	47 : TECHNOLOGICAL AND ERGONOMIC CHANGE [view]	Information Sources	

Linked?	HFE/E DISCIPLINE TAXONOMY	Linked to HSI - PSF CONCEPT MAP CONCEPT (part 1)	
N	47-01-00 : Resistance to and effects of change [view]		
N	47-02-00 : Introduction and strategies for introduction of change [view]		
N	47-03-00 : Evaluation and cost benefits of change [view]		
	HEALTH AND SAFETY		
Y	48 : GENERAL HEALTH AND SAFETY [view]	Temporary Physical & Mental State	Permanent Physical & Mental State
N	49 : ETIOLOGY [view]		
Y	49-01-00 : Individual differences [view]	Internal PSFs	
Y	49-02-00 : Information and communication design [view]	Information Sources	
Y	49-03-00 : Display and control design [view]	Computer Hardware	Tools
Y	49-04-00 : Workplace and equipment design [view]	Hardware	
Y	49-05-00 : Environmental design [view]	Workplace (Environment)	
Y	49-06-00 : Chemical hazards [view]	Chemicals (Workplace Env)	Air quality (Workplace Env)
Y	49-07-00 : Work design and organisational factors [view]	Task Design	Organization
Y	50 : INJURIES AND ILLNESSES [view]	Injury	Illness (temporary)
N	50-01 : Injuries resulting from accidents [view]		
N	50-02-00 : Effects on the visual system [view]		
N	50-03-00 : Effects on the auditory system [view]		
N	50-04-00 : Effects on other senses [view]		
N	50-05-00 : Effects on brain function [view]		
N	50-06-00 : Psychological disorders [view]		
N	50-07-00 : Effects on the cardiovascular system [view]		
N	50-08-00 : Effects on the respiratory system [view]		
N	50-09-00 : Effects on the digestive system [view]		
N	50-10-00 : Effects on the reproductive system [view]		
N	50-11-00 : Effects on the skin [view]		
N	50-12-00 : Effects on the musculo-skeletal system [view]		
	51 : PREVENTION [view]		
Y	51-01-00 : Health and safety propaganda [view]	Readiness for Duty (Int PSF)	Information Sources
Y	51-02-00 : Education, training and safety programmes [view]	Readiness for Duty (Int PSF)	Information Sources
Y	51-03-00 : Selection and screening for health and safety [view]	Internal PSFs	
Y	51-04-00 : Supervision for health and safety [view]	Policy	

Linked to HSI - PSF CONCEPT MAP CONCEPT (part 2)					
Wearable Hardware					
Illness (permanent)					

Linked?	HFE/E DISCIPLINE TAXONOMY	Linked to HSI - PSF CONCEPT MAP CONCEPT (part 1)	
Y	51-05-00 : Information and communication design for health and safety [view]	Information Sources	
Y	51-06 : Display and control design for health and safety [view]	Hardware	
Y	51-07-00 : Workplace and equipment design for health and safety [view]	Hardware	
Y	51-08-00 : Work design and organisation for health and safety [view]	Task Design	Task & Job
Y	51-09 : Clothing [view]	Policy	
Y	51-10 : Personal equipment [view]	Wearable	Tools
Y	51-11 : Emergency services [view]	Policy	Procedure, Instruction & Protocol
N	51-12-00 : Rehabilitation [view]		
	SOCIAL AND ECONOMIC IMPACT OF THE SYSTEM		
Y	52 : TRADE UNIONS [view]	Union	
Y	53 : EMPLOYMENT, JOB SECURITY AND JOB SHARING [view]	Temporary Physical & Mental State	
N	54 : PRODUCTIVITY [view]		
Y	54-01-00 : Absenteeism [view]	Workload	
Y	54-02-00 : Turnover [view]	Readiness for Duty (Int PSF)	Workload
Y	54-03-00 : Strikes [view]	Strike	
N	54-04-00 : Economic consequences [view]		
Y	55 : WOMEN AND WORK [view]	Gender	
Y	56 : ORGANISATIONAL DESIGN [view]	Organization (Team, ext PSF))	
Y	56-01-00 : Management [view]	Manager	
Y	56-02-00 : Industrial democracy and goal setting [view]	Goal	
Y	56-03-00 : Social interaction [view]	Another Actor	Team
N	56-04-00 : Industrial relations [view]		
Y	56-05-00 : Information systems and communication [view]	Information Sources	
Y	57 : EDUCATION [view]	Readiness for Duty (Int PSF)	Requirement
Y	58 : LAW [view]	Policy	
Y	59 : PRIVACY [view]	Internal PSFs	Layout
Y	60 : FAMILY AND HOME LIFE [view]	Internal PSFs	
Y	61 : QUALITY OF WORKING LIFE [view]	Internal PSFs	
Y	62 : POLITICAL COMMENT AND ETHICAL CONSIDERATIONS [view]	Internal PSFs	

Linked to HSI - PSF CONCEPT MAP CONCEPT (part 2)						
Computer Hardware						
Facility and Infrastructure						

Linked?	HFE/E DISCIPLINE TAXONOMY	Linked to HSI - PSF CONCEPT MAP CONCEPT (part 1)	
N	**METHODS AND TECHNIQUES**		
Y	65 : MEASURES [view]	Goal	Plan
N	65-02-00 : Time and speed [view]		
N	65-03-00 : Error, accuracy, reliability and frequency [view]		
N	65-04-00 : Event frequency [view]		
N	65-05 : Response operating characteristics [view]		
N	65-06-00 : Output and productivity [view]		
N	65-07-00 : Combined measures and indices [view]		
N	65-08 : Subjective measures [view]		

Linked to HSI - PSF CONCEPT MAP CONCEPT (part 2)						
Policy	Requirement					

BIBLIOGRAPHY

Adjibolosoo, S. B-S. K. (2004). The Human Factor Engineering Process: Preparing People for the Tasks and Challenges of Management. *Problems & Perspectives in Management* (2), 149-164.

Adler, P. S., Goldoftas, B., & Levine, D. I. (1997). Ergonomics, employee involvement, and the Toyota production system: a case study of NUMMI's 1993 model introduction. *Industrial and Labor Relations Review* 50, 416-437.

Attaran, M. (1996). Adopting an integrated approach to ergonomics implementation. *IIE Solutions*, 28(6), 18-23.

Austin, J., & Currie, B. (2003). Changing organisations for a knowledge economy: The theory and practice of change management. *Journal of Facilities Management*, 2(3), 229-243.

Axelsson, J.R.C., Bergman, B., Eklund, J. (1999, June), *Human Factors and Business Excellence* Paper presented at the International Conference on TQM and Human Factors, Linkoping, Sweden.

Bachimont, B., Isaac, A. & Troncy, R. (2002). Semantic commitment for designing ontologies: a proposal. Gómez-Pérez, A. and Benjamins, V. R. (Eds.): EKAW 2002, LNAI 2473, 114–121.

Barbiero, D. (n.d.) Tacit knowledge, in: *Dictionary of philosophy of mind*. Retrieved October 19, 2008, from http://philosophy.uwaterloo.ca/MindDict/tacitknowledge.html.

Baron, S. (2005). Control Systems R&D at BBN. *IEEE Annals of the History of Computing*, 27(2), 52-64.

Baneyx, A., Charlet, J. & Jaulent, M.C. (2007). Building an ontology of pulmonary diseases with natural language processing tools using textual corpora. *International Journal of Medical Informatics.* 76, 208-215.

Bencivenga, D. (1996). The economics of ergonomics: finding the right fit. *HR Magazine,* 41(8), 68-75.

Bergman, M. (2007). An intrepid guide to ontologies in *AI3 Adaptive information Adaptive Innovation Adaptive Infrastructure*. Retrieved September 5, 2008, from http://www. mkbergman.com/?m=200705.

Bijlsma-frankema, K. (2004). Dilemmas of managerial control in post-acquisition processes. *Journal of Managerial Psychology*, 19(3), 252-268.

Blomqvist, E. (2008, March). *Pattern ranking for semi-automatic ontology construction*. Paper presented at the 2008 ACM Symposium on Applied Computing, Fortaleza, Ceara, Brazil.

Blomqvist, E. & Öhgren, A. (2008). Constructing an enterprise ontology for an automotive supplier. *Engineering Applications of Artificial Intelligence.* 21, 286 & 397.

Booher, Harold, (ed. 2003). *Handbook of human systems integration.* New Jersey, NJ: Wiley.

Brown, M. (1996). *Keeping Score: Using the Right Metrics to Drive World-Class Performance*, New York, NY: AMACOM.

Buckingham, M. & Coffman, C. (1999). *First, Break All the Rules*. New York, Simon & Schuster.

Ceniceros, R. (1997). Ergonomics programs sit well. *Business Insurance*, 31(44), 25-27.

Cowen, S., & Rummler, G. A. (1974). The Management of Change: Preparing For Automation. *Training & Development Journal,* 28(5), 42-48.

Davis, M. (2005). Business value of semantic technology, Preliminary findings. *Industry Advisory Council Emerging Technology (ET) SIG. Information Sharing & Collaboration Committee*. Retrieved from http://www.knowledgefoundations.com/pdffiles/Business Value_v2.pdf

DeGreene, K. (1973). *Sociotechnical Systems*. Englewood Cliffs, NJ: Prentice-Hall.

De Leenheer, P. & Christiaens, S. (2007, October). *Mind the gap! Transcending the tunnel view on ontology engineering.* Paper presented at the 2nd International Conference on the Pragmatic Web. Tilburg, The Netherlands.

Denkena B, & Apitz R. (2003, June). *Knowledge and product lifecycle support for extended enterprises*. Paper presented at the 9th International Conference on Concurrent Enterprising. Espoo, Finland.

Dietz, J.L.G. (2006). *Enterprise Ontology – Theory and Methodology*. Secaucus, NJ: Springer-Verlag New York, Inc.

Dietz, J.L.G. (2006). The Deep Structure of Business Processes. In *Communications of the ACM*. 49(5) 59-64.

Dietz, J.L.G. & A. Albani. (2005). Basic notions regarding business processes and supporting information systems, *Requirements Engineering*, 10(3), 175-183. London: Springer

Dietz, J.L.G., & Hoogervorst, J. A. P. (2008, March). *Enterprise ontology in enterprise engineering*. Paper presented at the 2008 ACM symposium on Applied Computing. Fortaleza, Ceara, Brazil.

Differential Ontology Editor (DOE). Retrieved September 5, 2008 from http://homepages.cwi. nl/ ~troncy/DOE/

Doe, P. J. (1994). Creating a resilient organization. *Canadian Business Review*, 21(2), 22-26.

Duffy, V. G. & Salvendy, G. (1999). The impact of organizational ergonomics on work effectiveness: with special reference to... *Ergonomics*, 42(4), 614-638.

Dzissah, J. S. (2001). *Methodology to simultaneously address organizational needs with respect to quality, ergonomics and safety*. Retrieved June 22, 2007, from ProQuest Digital Dissertations database.

Dzissah, J., Karwowski, W., Rieger, S., & Stewart, D. (2005). Measurement of management efforts with respect to integration of quality, safety and ergonomics issues in manufacturing industry. *Human Factors and Ergonomics in Manufacturing*, 15(2), 213-232.

Ergonomics Abstracts. ISSN: 1464-5084 (electronic). Taylor & Francis. Retrieved on September, 2008

Emory, F. E. and Trist, E. L. (1960). Sociotechnical systems. In C. W. Churchman and M. Verhulst (Eds.), *Management Science: Models and Techniques*, Vol 2. Oxford, UK: Pergamon.

Fallik, F. (1988). *Managing organizational change: human factors and automation*. Philadelphia, PA: Taylor & Francis.

Folds, D., Gardner, D., & Deal, S. (2008). Building up to the human systems integration demonstration. *Insight* 11(2), 15-18.

Fraser, T.M, et al. (1981). Design for work and use. *Case studies in ergonomics practice (Vol 2)*. London, UK: Taylor & Francis.

Fraser, T. M., & Pityn, P.J. (1994). *Work, productivity, and human performance: Practical case studies in ergonomics, human factors, and human engineering*. Springfield, IL: C.C. Thomas.

Friedlander, M. A., & Evans, S. A. (1997, June). *Influence of organizational culture on human error*. Paper presented at the IEEE 6th Conference on Human Factors and Power Plants. Orlando, FL.

Gavriola, T., & Laird, D (2005, August). *Practical design of business enterprise ontologies.* Paper presented at the First International IFIP/WG 12.5 Working Conference: Industrial Applications of Semantic Web. Jyvaskyla, Finland.

Genaidy, A., Karwowski, W., & Christensen, D. (1999). Principles of work system performance optimization: A business ergonomics approach. *Human Factors and Ergonomics in Manufacturing*, 9(1), 105-128.

Genaidy, A., Karwowski, W., & Shoaf, C. (2002). The fundamentals of work system compatibility theory: An integrated approach to optimize human performance at work. *Theoretical Issues in Ergonomics Science*, 13, 317-330.

Genaidy, A., & Karwowski, W. (2003). Human performance in lean production environment: Critical assessment and research framework. *Human Factors and Ergonomics in Manufacturing*, 9(1), 105-128.

Genaidy, A., & Karwowski, W. (2007). The manufacturing enterprise diagnostic instrument: A tool for assessment of enterprise system manufacturers. *Human Factors and Ergonomics in Manufacturing*, 17(6), 521-574.

Genaidy, A., & Karwowski, W. (2008). A roadmap for a methodology to assess, improve and sustain intra- and inter-enterprise system performance with respect to technology-product life cycle in small and medium manufacturers. *Human Factors and Ergonomics in Manufacturing*, 18(1), 1-15.

Genaidy, A., Karwowski, W., Salem, S., Jarrel, J., Paez, O., & Tuncel, S. (2007). The work compatibility improvement framework: Defining and measuring the human-at-work system. *Human Factors and Ergonomics in Manufacturing*, 17(2), 163-226.

Genaidy, A., Salem, S., Karwowski, W., Paez, O., & Tuncel, S. (2007). The work compatibility improvement framework: An integrated perspective of the human-at-work system. *Ergonomics*, 50(1), 3-25.

Glendon, A.I., & Stanton, N.A. (2000) Perspectives on safety culture. *Safety Science,* 34 (1-3), 193-214.

Griffin, R. W. (2006). *Fundamentals of Management*. Boston, New York: Houghton Mifflin Company.

Gruber, T. R. (1993a). A translation approach to portable ontology specification. *Knowledge Acquisition,* 5(2): 119-220

Gruber, T. R. (1993b). Toward principles for the design of ontologies used for knowledge sharing. *International Journal Human-Computer Studies.* 43, 907-928.

Gruninger, M. & Fox, M.S. (1995, August). *Methodology for the design and evaluation of ontologies*. Paper presented at the Workshop on Basic Ontological Issues in Knowledge Sharing, IJCAI-95, Montreal, Canada.

Guarino, N. (1992). Concepts, attributes and arbitrary relations. *Data & Knowledge Engineering,* 8, 249-261.

Guarino, N. & Giaretta. (1995). Ontologies and knowledge bases. Towards a terminological clarification. Mars, N.J. (ed.), *Towards Very Large Knowledge Base.* Amsterdam: IOS Press.

Hartmann, J. et al (2005). Methods for ontology evaluation. *EU-IST Network of Excellence (NoE) IST-2004-507482 KWEB Deliverable D1.2.3* (WP 1.2).

Hasselhorn, T. (2000, August). *Successful change concepts in small- and medium-sized companies - A long-term perspective*. Paper presented at the XIVth Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Association, 'Ergonomics for the New Millennium'. San Diego, CA.

Hendrick, H. W. (1980, October). *Human factors in management.* Paper presented at the Symposium on Professional Planning,1980-2000 at the 24th Annual Meeting of the Human Factors Society, Los Angeles, CA.

Hendrick, H. W. (1984, October). *Wagging the tail with the dog*: *Organizational design considerations in ergonomics.* Paper presented at the Human Factors Society 28th Annual Meeting. Santa Monica, CA.

Hendrick, H. W. (1990). Factors affecting the adequacy of ergonomic efforts on large-scale-system development programs. *Ergonomics,* 33(5), 639-642.

Hendrick, H. W. (1991). Human factors in organizational design and management. *Ergonomics*, 34, 743-756.

Hendrick, H. W. (1997a). Good Ergonomics is Good Economics. Santa Monica, CA: *Human Factors and Ergonomics Society*.

Hendrick, H. W. (1997b). Organizational design and macroergonomics. In G. Salvendy (Ed), *Handbook of Human Factors and Ergonomics, 2nd Edition*. New York: Wiley, 594-636.

Hendrick, H.W. (2001). Macroergonomics: A Better Approach to Work System Design. *HFES Potomac Chapter Newsletter,* 36(6), 2-4

Hitchins, D. K. (2007). *Systems engineering: A 21st century systems methodology.* Chichester, England: Wiley.

Hoffman, R.R., Coffey, J.W., Ford, K.M. & Carnot, M. J. (2001, August). *STOFM-LK: A human-centered knowledge model for weather forecasting*. Paper presented at the Second Workshop on Interactive Meteorology and Oceanography, North Island Naval Air Station, CA.

Huang, N. & Diao, S. (2008). Ontology-based enterprise knowledge integration. *Robotics and Computer-Integrated Manufacturing, 24, 562–571.*

International Ergonomics Association (IEA). Retrieved September 6, 2008 from http://www.iea.cc/

INCOSE. [Web site] Retrieved May 8, 2008, from http://www.incose.org/

Imada, A. S., & Hubert, R. J. (1993, October). *Physical and psychological factors in perceived safety: a macroergonomic case study*. Paper presented at the 37th Annual Meeting of the Human Factors and Ergonomics Society. Seattle, WA.

Ingelgard, A. P. (1998). *On macroergonomics and learning strategies in improving working conditions*. Retrieved June 22, 2007, from ProQuest Digital Dissertations database.

Jussupova-Mariethoz, Y., & Probst, A. (2007). Business concepts ontology for an enterprise performance and competences monitoring. *Computers in Industry* 58, 118–129.

KAON Tool Suite [computer Software]. Retrieved September 10, 2008 from http://kaon. semanticweb.org/frontpage.

Kaplan, R., & Norton, E. (1998). *The Balanced Scorecard: Translating Strategy into Action.* Boston, MA: Harvard Business School Press.

Kaplan, R., & Norton, E. (2001). *The Strategy-Focused Organization: How Balanced Scorecard Companies Thrive in the New Business Environment*. Boston, MA: Harvard Business School Press.

Karwowski, W. (2005): The Discipline of Human Factors Engineering and Ergonomics. In Noy, Y. I. and Karwowski (Eds), *Handbook of Human Factors in Litigation*. Boca Raton, Florida: CRC Press.

Karwowski, W. (2005). Ergonomics and human factors: the paradigms for science, engineering, design, technology and management of human-compatible systems. *Ergonomics, 48(5),* 436-63.

Kaur, K., Forducey, P., Smith, L., & Scheideman-Miller, C. (2004). Organisational design and implementation of a telerehabilitation system in Oklahoma. *International Journal of Healthcare Technology & Management*, 6(1), 1.

Kennedy, C. (1994). Re-engineering: the human costs and benefits. *Long Range Planning,* 27, 64-72.

Kohn, J. P. (1997). *The ergonomic casebook: Real world solutions*. Boca Raton: CRC Press.

Kotzer, T. (2001). Management legend: trust never goes out of style. *Call Center Magazine*. 2.7, pp 27. Retrieved September 19, 2008 from http://www.callcentermagazine.com/article/ IWK20010604S0011

LaBar, G. (1995). What makes ergonomic teams work? *Occupational Hazards,* 57(2), 83-85.

Lame, G. (2003, June). *Using text analysis techniques to identify legal ontologie's components*. Paper presented at the ICAIL 2003 Workshop on Legal Ontologies & Web Based Legal Information Management. Edinburgh, Scotland

Landsburg, A. (2008). Human systems integration in commercial transportation. *Insight* 11(2), 35-38.

Levine, H. G., & Rossmoore, D. (1994, January). *Understanding the political threats to IT implementation: a case study*. Paper presented at the Hawaii International Conference on System Sciences. Wailea, HI.

Leppänen, M. (2007) A Context-Based Enterprise Ontology. *Lecture notes in Computer Science*. 4439, 273-286. W. Abramowicz (Ed.) New York, NY: Springer Berlin Heidelberg.

Li, Q., & Chen, Y. (2002, October). *Human factors analysis in CIM implementation*. Paper presented at the IEEE International Conference on Systems, Man and Cybernetics. Yasmine Hammamet, Tunisia.

Liu, C., Chen, W. & Han, Y. (2006, May). *DODO: A mechanism helping to dynamically construct domain ontologies for services integration*. Paper presented at the 2006 IW-SOSE. Shanghai, China.

Lizza, G., Lockett, J., & Narkevicius, J. (2008). Human systems integration: Synergy across the United States military services. *Insight* 11(2), 28-30.

Longmate, A. R. & Hayes, T. J. (1990). Making a difference at Johnson & Johnson: some ergonomic intervention case studies. *Industrial Management*, 32(2), 27.

Lynch-Caris, T. M. (2000). *Ergonomic justification through improved quantitative output measures.* Retrieved June 22, 2007, from ProQuest Digital Dissertations database.

Malaise, V., Zweigenbaum, P. & Bachimont, B. (2005). Mining defining contextts to help structuring differential ontologies. *Terminology.* 11(1), 21-53.

Martinsons, M. G., & Chong, P. K. C. (1999). The influence of human factors and specialist involvement on information systems success. *Human Relations* 52(1), 123-52.

Marx, A., & Van Hootegem, G. (2007). Comparative configurational case analysis of ergonomic Injuries. *Journal of Business Research,* 60(5), 522-530.

Maull, R. S., Weaver, A. M., Childe, S. J., Smart, P. A., & Bennett, J. (1995). Current issues in business process re-engineering. *International Journal of Operations & Production Management,* 15(11), 37-52.

Meister, D. (1971). *Human Factors: Theory and practice.* New York, NY: Wiley.

Miles, A. K. (2000). *The ergonomics and organizational stress relationship*. Retrieved June 22, 2007, from ProQuest Digital Dissertations database.

Miller, F.J. (2002). I = 0 (Information has no intrinsic meaning). *Information Research*, 8(1), paper no. 140. Retrieved September 19, 2008 from http://InformationR.net/ir /8-/paper140.html

Miller, D. P., & Swain A. D. (1987). Human error and human reliability. In Salvendy, G. (ed.). *Handbook of Human Factors*. Wiley, New York, 219-230.

Moray, N. (2000). Culture, politics and ergonomics. *Ergonomics* 43(7), 858-68.

Mueller, M. W. (2008). Human system integration – What's it all about? *Insight* 11(2), 7-10.

Muralidhar, A. (2008). How human systems integration and systems engineering can work together. *Insight* 11(2), 11-14.

Najjar, L. (2002). *The impact of information quality and ergonomics on service quality in the banking industry*. Retrieved June 22, 2007, from ProQuest Digital Dissertations database.

National Aeronautics and Space Administration (2008). *NASA's Root Cause Analysis Tool.*

Narkevicius, J. M., Winters, J., & Hardman, N. (2008). Talking the talk: Cross-discipline terminology challenges. *Insight* 11(2), 25-17.

Nedovic-Budic, Z., & Godschalk, D. R. (1996). Human factors in adoption of geographic information systems: a local government case study. *Public Administration Review (Washington, D.C.)* 56, 554-67.

Nonaka, I., & Takeuchi, H. (1995). *The knowledge creating company: how Japanese companies create the dynasties of innovation*. Oxford, UK: Oxford University Press.

Noy, N., & McGuinnes, L. (2001). *Ontology development 101: a guide to creating your first ontology*. Stanford Knowledge Systems Laboratory Technical Report KSL-01-05 and Stanford Medical Informatics Technical Report SMI-2001-0880.

Novak J.D. & Gowin D.B. (1984) *Learning how to learn.* New York and Cambridge, UK: Cambridge University Press.

Novak, J. D. (1998). *Learning, creating, and using knowledge*. Mahwah, NJ: Erlbaum.

Novak, J. D. (n.d.) *Concept Maps: What the heck is this?* Retrieved from https://www.msu.edu/~luckie/ctools/

Obrst, L. (2006a). *The Semantic Spectrum & Semantic Models*, [PowerPoint slides]. Retrieved from http://ontolog.cim3.net/file/resource/presentation/LeoObrst_20060112/Ontology SpectrumSemanticModels–LeoObrst_20060112.ppt.

Obrst, L. (2006b). *What is an Ontology? - A Briefing on the Range of Semantic Models*. [PowerPoint slides]. Retrieved from http://ontolog.cim3.net/cgi-bin/wiki.pl?Conference Call_2006_01_12.

Ontology Summit (2007). Ontology, taxonomy, folksonomy: Understanding the distinctions. Retrieved from http://ontolog.cim3.net/cgi-bin/wiki.pl?OntologySummit2007_ Communique.

Oxenburgh, M. (1991). *Increasing productivity and profit through health & safety*. North Ryde, N.S.W.: CCH International.

Padgham L, & Taylor G. (1997). A system for modeling agents having emotion and personality. In: Cavedon L, Rao A, Wobcke W (eds.) *Intelligent Agent Systems. LNAI 1209*, pp 59-71. New York, NY: Springer-Verlag Berlin.

Paez, O., Dewees, J., Genaidy, A., Tuncel, S., Karwowski, W., & Zurada, J. (2004). The lean manufacturing enterprise: An emerging sociotechnological system integration. *Human Factors and Ergonomics in manufacturing,* 14(3) 285-306.

Parker, K.G. (1995). Why ergonomics is good economic. *Industrial Engineering*, 41-46

Pater, R., Button, R. (1992). Organizing for strategic ergonomics (implementation of an effective ergonomics system). *Occupational Hazards,* 54(11), 55-59.

Paznik, M. J. (1986). Ergonomics does pay. *Administrative Management*, 47, 16-25.

Pedrinaci, C., Domingue, J., & de Medeiros, A. K. A. (2008). A core ontology for business process analysis. *Lecture Notes in Computer Science*. 5021, 49-64. (S. Bechhofer et al. Eds.) Springer Berlin / Heidelberg.

Perrow, C. (1999). *Normal accidents: Living with high-risk technologies*. New York, NY: Basic Books.

Peters, L. H. (2005). Quality of work life. *Blackwell Encyclopedic Dictionary of Human Resource Management*, 1-305.

Pfeffer. J. (1998), *The human equation: Building profits by putting people first*. Boston, MA: Harvard Business School Press.

Polanyi, M. (1958). *Personal Knowledge, Towards a Post Critical Philosophy.* Chicago, IL: University of Chicago Press.

Porter, M. E. (1996). What is strategy? *Harvard Business Review*, November-December, 61-78.

Pulat, M. & Alexander, D. C. (Eds.). (1991). *Industrial ergonomics: case studies*. New York, NY: McGraw-Hill.

Riel, P. F., & Imbeau, D. (1995). Making the best ergonomics investment. *IIE Solutions,* 27(6), 30-34.

Robbins, S. R. (1983). *Organization theory: The structure and design of organizations*. Englewood Cliffs, NJ: Prentice-Hall.

Rockefeller, K. A. (2002). *Evaluation of an ergonomic intervention in Washington state nursing homes.* Retrieved June, 2007, from ProQuest Digital Dissertations database.

Rogerson Jr, W. T., & Tremethick, M. J. (2004). Turning the Tide on Medical Errors in Intensive Care Units. *Dimensions of Critical Care Nursing*, 23(4), 169-175.

Roughton, J. (1993). Implementing an ergonomics program: developing procedures. *Industrial Engineering,* 25(9), 44-49.

Rowe, G., & Wright, G. (1999): The Delphi technique as a forecasting tool: issues and analysis. *International Journal of Forecasting*, 15(4), 353-375.

Roy, M.-C., Roy, K., & Bouchard, L. (1998). Human factors in business process re-engineering. *Human Systems Management*, 17(3), 193-204.

Sage, A.P. and Rouse, W. B. (1999). Information systems frontiers in knowledge management. *Information Systems Frontiers,* 1(3), 205-219.

Salem, S., Paez, O., Holley, M., Tuncel, W, Genaidy, A., & Karwowski, W. (2006). Performance Tracking Through the Work Compatibility Model. *Human Factors and Ergonomics in Manufacturing* 16(2), 133-153.

Schmager, B. (2000, August). *Integration of human factors and hazard analysis into human resource management.* Paper presented at the XIVth Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Association, Ergonomics for the New Millennium. San Diego, CA.

Schneider, F. (1995). Targeting ergonomics in your business plan. *Managing Office Technology,* 40(9), 28-31.

Scott, M. B. (2000). Ergonomic evaluations yield happier, healthier, more productive employees at low cost. *Employee Benefit Plan Review*, 54(9), 25-28.

Sell, R. C., et al. (1977). Human factors in work design and production. *Case studies in ergonomics practice (Vol 1).* London: Taylor & Francis, New York: Halsted Press.

Sgritta, T. A. (2008). New Tools for Strategic Planning. Lecture Notes from MGMT *3277, Entrepreneurship.* Department of Management at Belk College of Business Administration. University of North Carolina, Charlotte.

Sherehiy, B., & Karwowski, W. (2006). Knowledge Management for occupational safety, health and ergonomics. *Human Factors and Ergonomics in Manufacturing,* 16(3), 309-320.

Shoaf, C., Genaidy, A., & Karwowski, W. (2004). Improving the quality of work life: A model for organizational health assessment in emerging enterprises. *Human Factors and Ergonomics Manufacturing*, 14(1), 81-95.

Simon, J., Dos Santos, M., Fielding, J. & Smith, B. (2006). Formal ontology for natural language processing and the integration of biomedical databases. *International Journal of Medical Informatics.* 75, 224-231.

Sitzman, K. L. (2001). *Effective ergonomic teaching for positive client outcomes*. (M.S. dissertation, University of Utah College of Nursing, 2001).

Smith, B. (Producer): How to build an Ontology. *Ontology: an introduction*. Podcast retrieved from http://ontology.buffalo.edu/smith/articles/ontologies.htm. Preprint version of chapter Ontology, in L. Floridi (ed.), *Blackwell Guide to the Philosophy of Computing and Information*, Oxford: Blackwell, 2003, 155–166.

Spencer, T. (2006). Retooling at Fluor Hanford. *Occupational Health & Safety,* 75(6), 123-6.

Stanford Center for Biomedical Informatics Research (2007). Protégé (Version 3.4 beta) [Computer Software]. Available from http://smi.stanford.edu/projects/protege/

Stanger, L. W. (2002). *The prevention of injuries in manufacturing: Utilizing ergonomic interventions*. Retrieved June, 2008, from ProQuest Digital Dissertations database.

Stein, E. W. (1995). Social and individual characteristics of organizational experts. *International Journal of Expert Systems*, 8(2), 121-143.

Suryanto, H. & Compton, P. (2001, October). *Discovery of ontologies from knowledge bases*. Paper presented at the First International Conference on Knowledge Capture. Victoria, British Columbia, Canada.

Sveiby, Karl E (1997). Tacit Knowledge. Retrieved September 19, 2008, from http://www. sveiby.com/Portals/0/articles/Polanyi.html.

Traverso, P. et al (2002). *EDAMOK - Enabling Distributed and Autonomous Management of Knowledge.* Retrieved June, 2008, from http://edamok.itc.it/

TheBrain Technologies. (2007). PersonalBrain version 4.1.3.6 [Computer Software] Available from http://www.thebrain.com/#-47.

Farquhar, A. Fikes, R., & Rice, J. (n.d). The Ontolingua Server. Retrieved September 12, 2008 from http://pages.cpsc.ucalgary.ca/~kremer/KAW96/farquhar/kaw-96-demo-final.html

Thurman, J. et al. (1993). *On Business and Work.* International Labour Office, Geneva.

Thronesbery, C., Malin, J., Holden, K., & Smith, D.P. (2006, March). *Tools to support human factors and systems engineering interactions during early analysis*. Paper presented at the 2006 IEEE Aerospace Conference. Big Sky, Montana.

UK Ministry of Defence (2008). *About the Human Factors Integration Defence Technology Centre.* Retrieved August, 2008 from http://www.hfidtc.com/about_HFI.htm.

U.S. Army. (2005). *Manpower and personnel integration (MANPRINT) handbook*. Washington, DC: US Government Printing Office.

U.S. Federal Aviation Administration. (2005). *FAA Order 9550.8A: Human Factors Policy*. Washington, DC: US Government Printing Office.

U.S. Department of Defense. (1999). *MIL-HDBK-46855a: Human engineering program process and procedures*. Washington, D.C: US Government Printing Office.

U.S. Department of Defense Directive (DoDD) 5000.1. (2003). *The defense acquisition system*. Washington, DC: US Government Printing Office.

U.S. Department of Defense. (1983). *MIL-STD-1472D: Human Engineering Design Criteria for Military Systems, Equipment and Facilities*. Washington, DC: US Government Printing Office.

U.S. Navy. (1998). *SC-21 S&T Manning Affordability Initiative (SC-21/ONR): Human engineering process.* Washington, DC: US Government Printing Office.

U.S. General Accounting Office. (1997). *Worker protection: Private sector ergonomics programs yield positive results: Report to congressional requesters*. Washington, DC: US Government Printing Office.

Uschold, M., King, M., Moralee, S. & Zorgios, Y. (1998). The enterprise ontology. *The Knowledge Engineering Review*. 13(1), 31-89.

Uschold, M. & Tate, A. (1998). Putting ontologies to use. *The Knowledge Engineering Review*. 13(1), 1-3.

Van der Aalst, W.M.P. et al. (2007) Business process mining: An industrial application. *Information Systems,* 32(5), 713–732.

Van Elst L., Abecker A., & Maus H. (2001, July). *Exploiting User and Process Context for Knowledge Management Systems*. Paper presented at the Workshop on User-Modeling for Context Aware Applications at the 8th International Conference on User Modeling. Sonthofen, Germany.

Vasilash, G. S. (1990). Designing better places to work. *Production*, 102(2), 56-60.

Vavra, B. (2003). Getting ergonomics down to size. *Safety & Health***,** 167(6), 40.

Versteeg, G. & Bouwman, H. (2006). Business architecture: A new paradigm to relate business strategy to ICT. *Information Systems Frontiers.* Springer. 8, 91-102.

Vicente, K.J. (2007). Human factors engineering that makes a difference: leveraging a science of societal change. *Theoretical Issues in Ergonomics Science*, 9(1), http://www.informaworld.com/smpp/title~content=t713697886~db=all~tab=issueslist~branches=9 - v9 1-24.

Webster. (1989). *Webster's Encyclopedic Unabridged Dictionary of the English Language*. New York, NY: Gramercy Books.

Weeks, B., Helms, M. M., & Ettkin, L. P. (1995). Are we ready for TQM? A case study. *Production and Inventory Management Journal*, 36(4), 27-32.

Wilson, J. R., Farrington-Darby, T., Cox, G., Bye, R., & Hockey, G. R. J. (2007). The railway as a socio-technical system: human factors at the heart of successful rail engineering. *Journal of Rail & Rapid Transit*, 221(1), 101-115.

Wilson, T.D. (2002). "The nonsense of 'knowledge management'". *Information Research*, 8(1), paper no. 144.

Workplace ergonomics. (1999). *Occupational Health & Safety,* 68(1), 75-84.

Zacarias, M., Caetano, A., Pinto, H. S., & Tribolet, J. (2005). Modeling contexts for business process oriented knowledge support. In K.-D Althoff, et al. (Eds.), *Professional Knowledge Management*. 3782, 431-442. New York, NY: Springer-Verlag Berlin Heidelberg.

Zink, K. J. (2005). From industrial safety to corporate health management. *Ergonomics*, 48(5), 534-546.

Zink, K.J. (2006). Human factors, management and society. *Theoretical Issues in Ergonomics Science*, 7(4), 437-445.

Zur Muehlen, M. (2004). Workflow-based process controlling. Foundation, design, and implementation of workflow-driven process information systems. *Advances in Information Systems and Management Science, Volume 6*. Berlin: Logos.