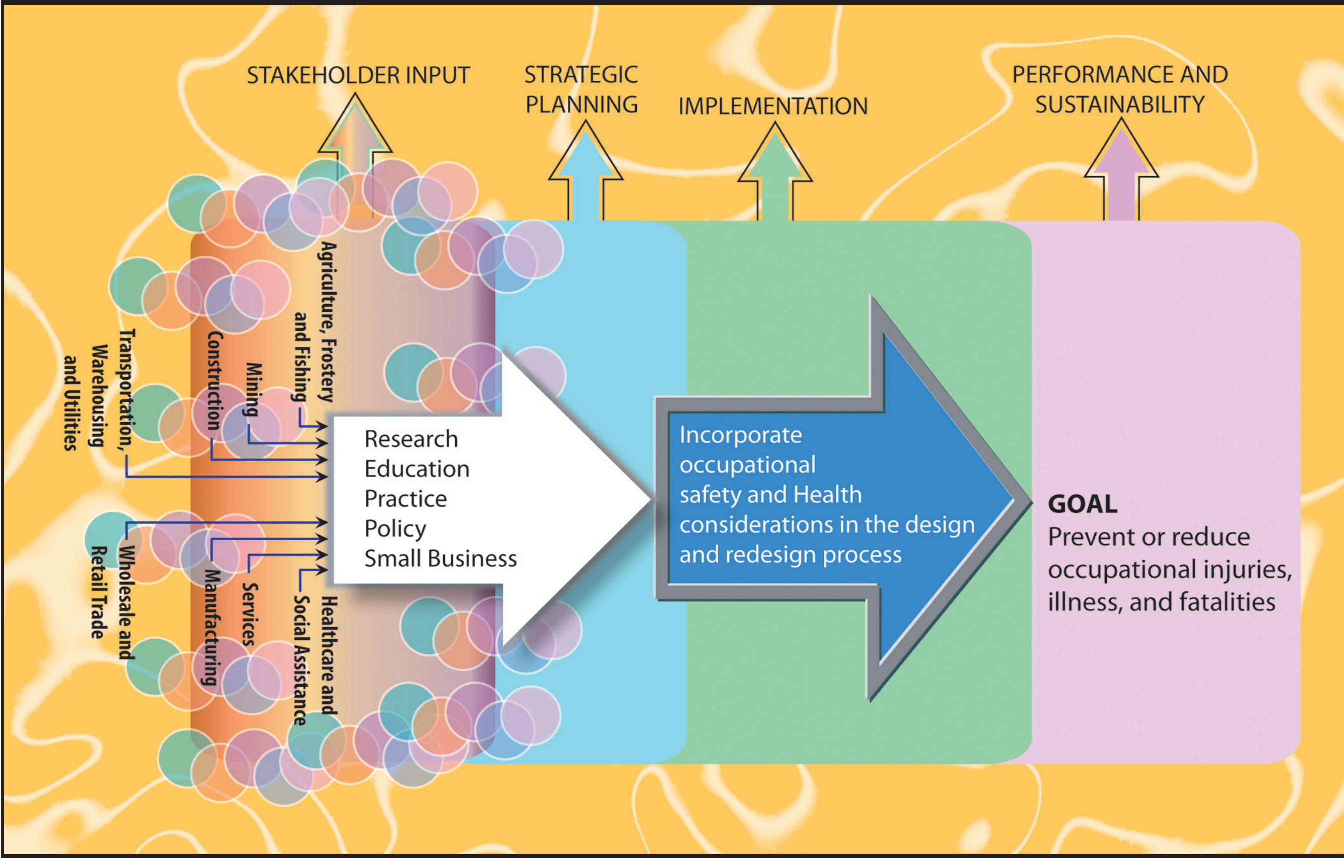
PREVENTION THROUGH DESIGN:

TRANSDISCIPLINARY PROCESS



Atila Ertas

Prevention through Design:
Transdisciplinary Process

Atila Ertas

Professor and Director of
Academy of Transdisciplinary Studies
Texas Tech University
Mechanical Engineering Department
Lubbock, Texas 79409

TheATLAS

TheATLAS Publishing

TheATLAS Publishing

Copyright © 2010 by TheATLAS Publishing

All rights reserved. No part of this publication may be reproduced, stored in retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior permission of TheATLAS Publishing.

ISBN: 0-9778129-4-4; doi: 10.22545/2021b/B11

Published in the United States of America by

TheATLAS

www.theatlas.org

Acknowledgments

Funding for this research was provided by the National Institute for Occupational Safety and Health under the National Occupational Research Agenda, Prevention through Design Initiative.

Prevention through Design (PtD):
Transdisciplinary Process

Summary

In July 2007, NIOSH sponsored *Prevention through Design* (PtD) Workshop, which concluded that there was a critical need to include PtD in the education of engineers. The main objective of this module is to introduce the concept of Prevention through Design to prevent occupational injuries, illnesses, and fatalities to freshman engineers in the introduction to design course. Students should emerge from this transdisciplinary education with a broad perspective of occupational safety and health needs in the design process to prevent or minimize the work-related hazards. Similarities between transdisciplinary process and Prevention through Design concept also introduced and discussed.

Table of Contents

1.1 Introduction

During the last decade, the number of complex problems facing engineers has exploded, and the technical knowledge and understanding in science and engineering required to address and mitigate these problems is rapidly evolving. The world is becoming increasingly interconnected as new opportunities and highly complex problems connect the world in ways we are only beginning to understand. When we do not solve these problems correctly and in a timely manner, they rapidly become crises. Problems, such as energy shortages, pollution, transportation, the environment, natural disasters, safety, health, hunger and the global water crisis, threaten the very existence of the World as we know it today. Recently, fluctuating fuel prices and environmental concerns have sent car manufacturers in search of new, zero polluting, fuel-efficient engines. None of these complex problems can be understood from the sole perspective of a traditional discipline. The last two decades of designing large–scale engineering systems have demonstrated that neither mono–disciplinary nor inter– or multi–disciplinary approaches provide an environment that promotes the collaboration and synthesis necessary to extend beyond existing disciplinary boundaries and produce truly creative and innovative solutions to large–scale, complex problems. These problems include not only the design of engineering systems with numerous components and subsystems which interact in multiple and intricate ways; they also involve the design, redesign and interaction of social, political, managerial, commercial, biological, medical, etc. systems. Furthermore, these systems are likely to be dynamic and adaptive in nature. Solutions to such unstructured problems require many activities that cut across traditional disciplinary boundaries: that is, transdisciplinary research and education.

The results of transdisciplinary research and education are: emphasis on teamwork, bringing together investigators from diverse disciplines, developing and sharing of concepts, methodologies, processes, and tools; all to create fresh, stimulating ideas that expand the boundaries of possibilities. The transdisciplinary approach creates a desire in people to seek collaboration outside the bounds of their professional experience to make new discoveries, explore different perspectives, express and exchange ideas, and gain new insights.

The main objective of this module is to introduce the concept of Prevention through Design to prevent occupational injuries, illnesses, and fatalities. Students should emerge from this transdisciplinary educational experience with a broad perspective of occupational safety and health needs in the design process, in order to prevent or minimize work-related hazards.

1.2 Transdisciplinarity and Prevention through Design

1.2.1 Discipline

For the many years since the 1950s, the integration of research methods and techniques across disciplines has been of great interest in the social and natural sciences [1]. A particular area of study is called a "discipline" provided it has cohesive tools, specific methods and a well developed disciplinary terminology. Since disciplines inevitably develop into self–contained shells, interaction with other disciplines is minimized. However, practitioners of a discipline develop effective intra–disciplinary communication based on their disciplinary vocabulary. Many distinguished researchers and educators contributed to the development of transdisciplinary education and research activities [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20].

Multidisciplinary activities involve researchers from various disciplines working essentially independently, each from their own discipline specific perspective, to solve a common problem. Multidisciplinary teams do cross discipline boundaries; however, they remain limited to the framework of disciplinary research.

In Interdisciplinary activities, researchers from diverse disciplines work jointly on common problems by exchanging methods, tools, concepts and processes among them to find integrated solutions. Both multidisciplinary and interdisciplinary activities overflow discipline boundaries but their goal remains within the framework of disciplinary research.

1.2.2 Defining Transdisciplinarity

In the German-speaking countries the term transdisciplinarity is used for integrative forms of research [21]. Transdisciplinary education and research programs take collaboration across discipline boundaries a step further than do multidisciplinary and interdisciplinary programs. The transdisciplinary concept is a process by which researchers representing diverse disciplines work jointly to develop and use a shared conceptual framework to solve common problem. A central hallmark of transdisciplinary research is the loosening of theoretical models and the development of a new conceptual synthesis of common terms, measures, and methods that produce new theories and models [22]. The three terms of: multidisciplinary, interdisciplinary and transdisciplinary, are often defined differently among researchers and educators.

Nicolescu (2005) stated that transdisciplinarity concerns that which is at once between the disciplines, across the different disciplines, and beyond all disciplines [23].

Klein (2004) defined the terminology of multidisciplinary, interdisciplinary and transdisciplinary approaches as [8]: "Multidisciplinary approaches juxtapose disciplinary/professional perspectives, adding breadth and available knowledge, information, and methods. They speak as separate voices, in encyclopedic alignment…"

"Interdisciplinary approaches integrate separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of complex issues, questions, or problem… Theories of interdisciplinary premised on unity of knowledge differ from a complex, dynamic web or system of relations."

"Transdisciplinary approaches are comprehensive frameworks that transcend the narrow scope of disciplinary world views through an overarching synthesis, such as general systems, policy sciences, feminism, ecology, and sociobiology…" "All three terms evolved from the first OECD international conference on the problems of teaching and research in universities held in France in 1970."

Hadorn, H. G et al., stated that: "Transdisciplinary research is research that includes cooperation within the scientific community and a debate between research and the society at large. Transdisciplinary research therefore transgresses boundaries between scientific disciplines and between science and other societal fields and includes deliberation about facts, practices and values," [24].

Peterson and Martin (2005) stated that interdisciplinary research has not produced a combination or synthesis which would go beyond disciplinary boundaries to produce innovative solutions to policy questions. However, transdisciplinary approaches call for a synthesis of research at the stages of conceptualization, design, analysis, and interpretation by integrated team approaches [25].

D. Stokols et al., defined transdisciplinary science as collaboration among scholars representing two or more disciplines in which the collaborative products reflect an integration of conceptual and/or methodological perspectives drawn from two or more fields [26].

"One of the broadly agreed characteristics of transdisciplinary research is that it is performed with the explicit intent to solve problems that are complex and multidimensional, particularly problems (such as those related to sustainability) that involve an interface of human and natural systems" [27].

During the past decade, other different approaches of transdisciplinarity were developed and described by several distinguished researchers and educators. From the definitions above, one can easily see that phrases of collaboration, shared knowledge, unity of knowledge, distributed knowledge, common knowledge, and integration of knowledge, integrated disciplines, beyond discipline, complex problems, and societal fields are the common ones. Although a precise definition of transdisciplinarity is debatable, reviewing the above approaches, definitions, and common phrases, transdisciplinarity may be defined as [19, 20]:

Transdisciplinarity is a development of new knowledge, concepts, tools & technologies shared by researchers from different family of disciplines (Social science, natural science, humanities and engineering). It is a collaborative process of a new way of organized knowledge generation and integration by crossing disciplinary boundaries for designing and implementing solutions to unstructured problems.

Transdisciplinary Knowledge is a shared, common collection of knowledge from diverse disciplinary knowledge cultures (engineering, natural science, social science and humanities).

The *Transdisciplinary Research Process* can be defined as collaboration among scholars from diverse disciplines to develop and use integrated conceptual frameworks, tools, techniques and methodologies to solve common unstructured research problems. Transdisciplinary research leads to a creation of new paradigms and provides pathways to new frontiers.

Key centers of attention and characteristics of transdisciplinary research are:

- Use of shared concepts, frameworks, tools, methodologies and technologies to solve common unstructured research problems,
- Eliminates disciplinary boundaries for strong collaboration,
- Redefines the boundaries of natural science, social science, humanities and engineering by bridging them,
- Leads for the development of new shared common conceptual frameworks, tools, methodologies and technologies.

1.2.3 Multidisciplinary, Interdisciplinary and Transdisciplinary Case Study [19]

Wind power promises a clean and inexpensive source of electricity. It promises to reduce our dependence on imported fossil fuels and to also reduce the output of greenhouse gases. Many countries are, therefore, promoting the construction of vast wind 'farms' and encouraging private companies with generous subsidies. The U.S. Department of Energy (DOE) goal is to see 5 percent of our electricity produced by wind turbine farms in 2010. The history of wind power shows a general evolution from the use of simple, light-weight devices to heavy, material-intensive drag devices and finally to the increased use of light-weight, material-efficient aerodynamic lift devices in the modern era.

During the winter of 1887-88, Charles F. Brush built the first automatically operating wind turbine for electricity generation. It was the world's largest wind turbine with a rotor diameter of 17 m (50 ft.) and 144 rotor blades made of cedar wood. The turbine ran for 20 years and charged the batteries in the cellar of Brush's mansion [28].

The wind has been an important source of energy in the U.S. for some time. Over 8 million mechanical windmills have been installed in the United States since the 1860s. It is interesting to note that some of these units have been in operation for more than a hundred years [29].

A wind turbine system design consists of sub-systems to catch the energy of the wind, to point the turbine into the wind, to convert mechanical rotation into electrical power; as well there are systems to start, stop, and control the turbine. To design today's impressive and giant wind turbine structures, many researchers from different disciplines collaborate and work together. Among them, mechanical engineers work on gear design, civil engineers work on structure design, material engineers work on the most suitable material selection for the application, electric engineers work on power transmission and control system design, and finally, wind engineers work on rotor blade design, etc. A simple methodology could be to create a collaborative research team to design wind turbines efficiently. Of course, the collaborative effort can be organized many different ways. The first approach that comes to mind could be the multidisciplinary research process.

Multidisciplinary activities involve researchers from various disciplines working essentially independently, each from his/her own discipline specific perspective, to address a common problem. Multidisciplinary teams do cross discipline boundaries; however, they remain limited to the framework of disciplinary research.

Assume that engineers from diverse disciplines attempt to design a wind turbine. As shown in Figure 1.1, the common research problem is to design a wind turbine. As mentioned previously, mechanical engineers work on gear design, civil engineers work on structure design, material engineers work on most suitable material selection for the application, electric engineers work on power transmission and control system design and finally, wind engineers may work on rotor blade design and deliver their sub-product design independently and the whole system will be put together. The question is: is this process providing an optimum design? The answer is obviously no! Maybe better collaboration and organization is necessary for this kind of complex system design.

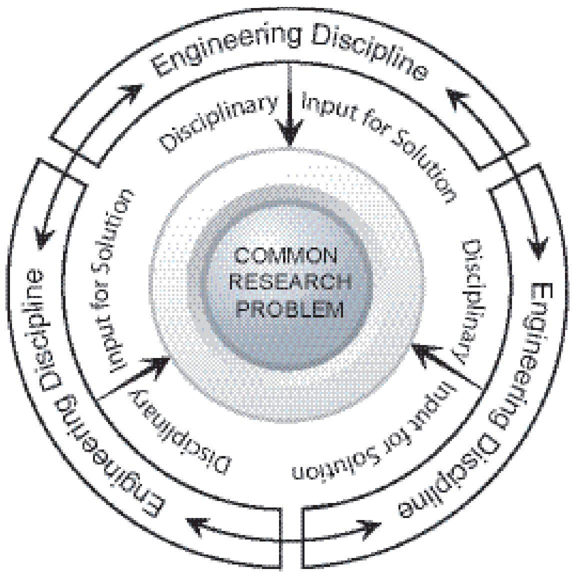


Figure 1.1 Multidisciplinary Research Process.

If the research approach is interdisciplinary, as shown in Figure 1.2, researchers from different disciplines start communicating and collaborating with each other to optimize their sub-component design considering the whole system design requirements. Once the compatibility and reliability of the sub-components are ensured, then they are delivered for assembly of the system. This provides an integrated solution to a common problem.

As mentioned previously, after the sub-product designs are delivered independently, the entire system can then be assembled. The question is: is this process providing an optimum design? Again, the answer perhaps would be no.

Although wind power promises a clean and inexpensive source of electricity, it can raise environmental and community concerns. For example:

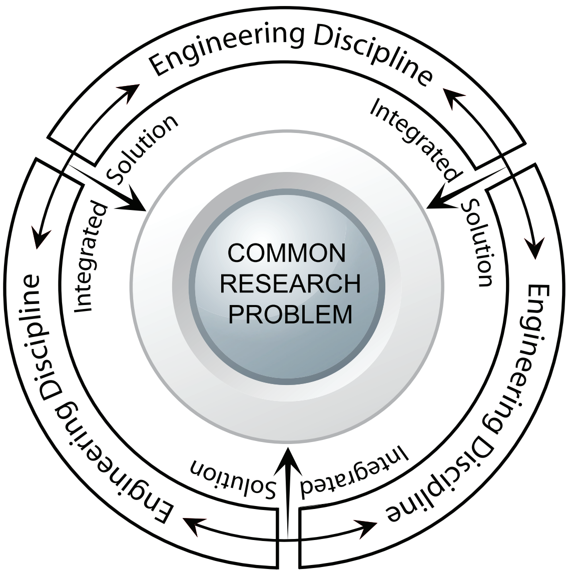
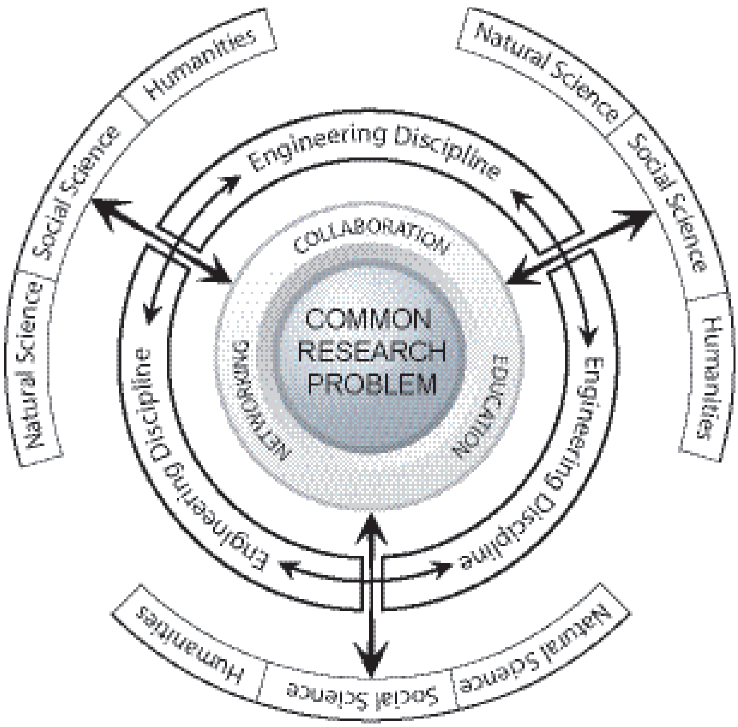


Figure 1.2 Interdisciplinary Research Process.

- noise and vibrations caused by wind turbines may cause sleep disruptions and other health problems among people who live nearby,
- they can be visually intrusive for residents living near them,
- they can disturb wildlife habitats and cause injury or death to birds,
- turbulence from wind farms could adversely affect the growth of crops in the surrounding countryside,
- they may pose significant threats to migrating birds,
- having huge wind turbines, each standing taller than a 60-story building and having blades more than 300 feet long may disturb the community residence.

In the late 1980s, the California Energy Commission reported 1,300 birds were killed by wind turbines, including over 100 golden eagles at Altamont Pass, CA. Environmental issues related to wind turbines include: impacts on wildlife, habitat, wetlands, dunes, and other sensitive areas such as water resources, soil erosion and sedimentation. There are many other areas



of strong concern. They are: interference with TV reception, microwave reception interference, depreciating property values, increased traffic, road damage, cattle being frightened from rotating shadows cascading from the blades in a setting sun, rotating shadows in nearby homes, concerns about stray voltage, concerns about increased lightning strikes and many others. Currently, all of these issues are being raised in states where wind farms have been introduced.

As shown in Figure 1.3, this process involves not only crossing engineering disciplinary boundaries but also requires crossing families of disciplinary boundaries (engineering, social science, natural science, and humanities). Social Sciences and the Humanities bring an abundance of knowledge on cultural, economic and social growth and advancement as well as on social system. Therefore, they provide an important input to decisions being made relative to current problems and challenges. The Humanities play an important role putting to beneficial use new findings in engineering and the natural sciences. For example, natural scientists work together with researchers in the humanities to discover archeological objects and determine their age.

In the case of wind turbine design, researchers from environmental science should undertake an environmental assessment of the site and a comprehensive consultation exercise with local community and environmental bodies in terms of development of the wind turbine farms. Engineers should work with researchers from social science, natural science, and humanities to understand the impact on the environment and nearby communities of people to guide reiteration of their design.

Through the transdisciplinary research process the researchers can plan early and have frequent consultations with the affected communities. This allows them to identify and address the most serious issues before substantial investments are made. In other words, designers should make reasonable efforts to "design out" or minimize hazards and risks early in the design process.

Further, researchers from diverse disciplines should collaborate and work together with the required utility agencies, government agencies, environmental organizations, and with the developers to insure that such complex problems will be under control.

Continuous education and encouragement is required to development a spirit of collaboration among the research members in order to solve complex problems. Through educational activities that focus on such areas as research team management, problem solving, establishing research goals, optimizing the use of resources, and supporting each other, members of the research team learn to work together more effectively. In other words, team members provide mentoring and support to each other. For transdisciplinary teams to be effective, they must meet on a regular basis.

Members of transdisciplinary teams have an enlarged information network and extended contacts who are capable of collaborating on a project from beginning to implementation. A transdisciplinary research community is a network of the minds of researchers from diverse disciplines.

As shown in Figure 1.3, collaboration, networking and education on a global scale are the keys to solving the complex problems and issues facing humankind in this century. The successful development of a network of global collaboration centers and institutes would provide a common sharing of knowledge and benefit everyone by significantly enhancing the ability to solve the unstructured problems the world is facing today.

1.2.4 Why Prevention through Design is Transdisciplinary Process ?

Paul Schulte, Director, Education and Information Division, NIOSH stated that the "Prevention through Design (PtD) process is a collaborative initiative that lies on the principle that the best way to prevent occupational injuries, illnesses, and fatalities is to anticipate and "design-out" or minimize hazards and risks when new equipment, processes, and business practices are developed," [30]. He also emphasized that the PtD process requires cross-disciplinary activities.

June M. Fisher reported that: "Implementing PtD will require the challenging transformative concept. Transformative changes are more broad and can lead to new forms and practices that guide us to safer and more productive environments. PtD, if viewed and practiced with broad vision, should further transformative changes that promote patient, worker, and environmental safety," [31]. A number of similarities exist between transformative and transdisciplinary concepts.

Schulte et al. clearly stated that: "An important element that should be included in the initiative is the need for global cooperation or harmonization. Due to the global influence on economies, workplaces, designs, and occupational safety and health, any major initiative, such as PtD, needs to have global input and support," [32]. Since PtD directly and indirectly involves with global issues, strong international collaborations and partnerships need to be established among stakeholders to have global input and support for PtD. This important observation reveals that PtD is a transnational activity.

The American workforce undergoes significant change because of immigration. Immigrants with job opportunities in the US usually have lower educational skill, greater poverty, and less income than the native-born population. In this situation, the difficulties of developing culturally integrated approaches to workplace safety and health should not be underestimated. As the world becomes increasingly multicultural, PtD process should consider synthesized transcultural theories, models, and research, to facilitate culturally harmonious and capable prevention and control of occupational injuries, illnesses, and fatalities.

Above discussions revel that PtD is a shared concept crossing many diverse disciplines including; agriculture, forestry and fishing; construction; health care and social assistance; manufacturing; mining; services; transportation, warehousing, and utilities; and wholesale and retail trade. A common research problem, which will be addressed by PtD associated with all the sectors from many different disciplines, is preventing and controlling occupational injuries, illnesses, and fatalities.

In summary, Prevention through Design is a transdisciplinary process that involves many transnational and transcultural issues.

1.2.5 PtD Considerations for the Design Process

1.2.5.1 Generic Design Process

The typical steps in the engineering design process are as shown in Figure 1.4. The generic design process shown in the figure is considered to be generally applicable to most design efforts, but the reader should recognize that individual projects often require variations, including the elimination of some steps.

Recognition of Need and Requirements
The design process begins with an identified need, which can be satisfied by the defined design requirements such as customer requirements, design requirements, and functional requirements. During this phase, the design team works closely with the customer to determine the requirements for the product. The requirements phase identifies the functionality, performance levels, and other characteristics which the product must satisfy in order to be acceptable to the customer. The requirements developed in this phase serve as a foundation for the remaining phases of the design process. It is important to note that establishment of the valid design requirements will be revisited and performed during the preliminary design phase.

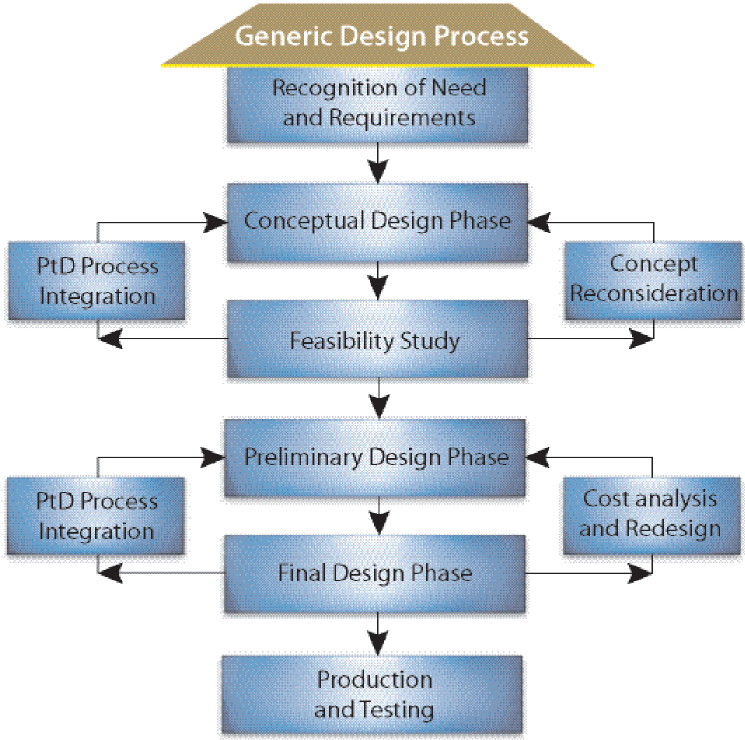


Figure 1.4 Generic Design Process (adapted from Ertas & Jones [33]).

Conceptual Design Phase

After the problem has been completely defined, during the concept development, viable solutions need to be identified from which the optimum approach can be selected. Assessment of the feasibility of the selected concept(s) is often accomplished as part of the conceptualization task on reasonably small projects but is usually a major element of the overall program on larger projects and sometimes it may take several years to complete. The goal of assessing the feasibility of the concept ensures that the project proceeds into the design phase with a concept that is achievable, both technically and within cost constraints, and that new technology is required only in areas that have been thoroughly examined and agreed to. It is important to have research team members with broad experience and good judgment involved in the feasibility assessment phase of the design process. Team members in charge of the feasibility study effort should be directly responsible for the overall (cradle to the grave) performance and functionality of the product, process or facility-people whom have a work ownership mentality.

Preliminary Phase

The preliminary design phase may also be known as architectural design. The preliminary phase of the design process bridges the gap between the design concept and the detailed design phase of the effort. The design concept is further defined during the preliminary design and, if more than one concept is involved, an assessment leading to the selection of the best overall solution must be performed. System-level and, to the extent possible, component level design requirements should be established during this phase of the process. The overall system configuration is defined during the preliminary design phase and a schematic, diagram, layout, drawing or other engineering documentation should be developed to provide early project configuration control. The overall system configuration is defined during this phase and a schematic, diagram, or layout definition drawing or other engineering documentation (depending on the project) should be developed to provide early project configuration control. This documentation will assist in ensuring interdisciplinary or transdisciplinary team integration and coordination during the detail design phase. The preparation of system testing and operational and maintenance procedures at an early stage in the design often helps in that regard. The process of thinking these procedures through may help in quantifying the various design parameters and thus provide a valid basis for component design.

Detailed Design Phase

The goal of the detailed design phase is to develop a system of design drawings and specifications that completely provides a detailed specification for each component, thoroughly describing interfaces and functions provided by each component so that can be manufactured. At this design phase all the designers and researchers from diverse disciplines are actively involved in the synthesis/analysis process, resolving the system design concept into its component parts, evaluating components to validate previously established requirements and specifying those design requirements left undefined, and assessing the affect of the component requirements on the overall system requirements. The detailed design phase will serve as the basis for the production phase.

Production and Testing Phase

During this phase of the project, using the specifications created in the previous phases, the actual product is developed and manufactured. The final product will then be tested to ensure that it meets the requirements defined in the Requirements phase. As shown in Figure 1.4, Prevention through Design should be an important consideration throughout the design process.

1.2.5.2 PtD Process

The goal of this section is the integration of Prevention through Design (PtD) considerations into design activities during the conceptual, preliminary, and final design stages. Figure 1.5 shows a general process for Prevention through Design; namely, define the work related to product design then identify and evaluate potential safety hazard and injuries involved with the product, and finally control hazards that cannot be eliminated. This activity should be implemented throughout the entire design process as shown in Figure 1.4.

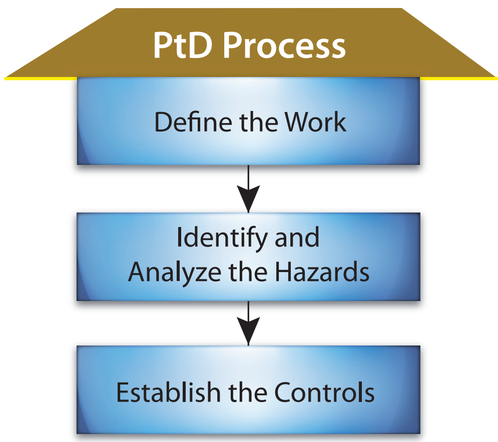


Figure 1.5 PtD Process.

PtD must be fully integrated in the early design process in the project. Namely, by the start of the concept development, a hazard analysis of alternatives to be considered and worker safety and health requirements for the design must be established. The main objective of PtD at the conceptual design phase is to evaluate alternative design concepts, to plan to protect workers safety and health from hazards and to provide a conservative safety design basis for a chosen concept to carry on into preliminary design. The conceptual design phase offers a key prospect for the safety and health hazard analysis to influence the product design.

Prevention through Design efforts during the preliminary design phase are planned to be incremental instead of a complete re-examination of the conceptual design. The hazard analysis will progress from a facility level analysis to a system level hazard analysis as design detail becomes available. When the hazard analysis is developed, the selection of controls, safety considerations, and classifications developed during the conceptual design phase must be revisited to make sure they are still appropriate. Decisions made during the preliminary design phase provide the basis for the approach to detailed design and production.

During the detailed design phase based on hazards and accident analysis of the final design, a final set of hazard controls will be developed. More detailed information on this subject can be found elsewhere [34].

The National Safety Council has recommended basic guidelines for designers to ensure acceptable safety and health for products and processes. The guidelines given below are broad, and as many as possible should be considered during product design and use [33]:

- Eliminate hazards by changing the design, the materials used, or the maintenance procedures.
- Control hazards by capturing, enclosing, or guarding at the source of the hazard.
- Train personnel to be cognizant of hazards and to follow safe procedures to avoid them.
- Provide instructions and warnings in documentation and post them in appropriate locations.
- Anticipate credible abuse and misuse and take appropriate action to minimize the consequences.

- Provide appropriate personal protective equipment and establish procedures to ensure that it is used as required.

Engineers must be able to identify hazards related with their product designs and to quantify the relative severity and probability of occurrence. Safety hazards normally result in accidents that occur over a relatively short period of time and for which the severe effects are readily apparent. The effects of health hazards, in contrast, may not be obvious for some time, often months or years, but the results can be just as damaging [35]. A number of techniques have been proposed as aids in the process of recognizing, quantifying, and reducing hazards. Haddon's 10 rules given below comprise one of the more commonly recognized strategies [36]:

1. Prevent the creation of the hazard (e.g., prevent the production of hazardous and nonbiodegradable chemicals).
2. Reduce the magnitude of the hazard (e.g., reduce the amount oflead in gasoline).
3. Eliminate hazards that already exist (e.g., ban the use of chlorofluorocarbons).
4. Change the rate of distribution of a hazard (e.g., control the rate of venting a hazardous propellant).
5. Separate the hazard from that which is being protected (e.g., store flammable materials at isolated locations).
6. Separate the hazard from that which is being protected by imposing a barrier (e.g., separate fuel and oxidizer storage areas by using berms or other barriers).
7. Modify basic qualities of the hazard (e.g., use breakaway roadside poles).
8. Make the item to be protected more resistant to damage from the hazard (e.g., use fabric materials in aircraft that do not create toxic fumes when combusted).
9. Counter the damage already done by the hazard (e.g., move people out of a contaminated area).
10. Stabilize, repair, and rehabilitate the object of the damage (e.g., rebuild after a fire).

Even though the above guidelines and rules do not include every possible safety consideration in a design project, they do provide a checklist against which the design can be evaluated and modified as needed. The designer must develop the habit of continuously evaluating the design for safety, considering not only the product design itself but the workers involved in fabricating the product, maintaining and repairing the product or system, as well as the end user or purchaser.

Developing the manufacturing processes as well as the maintenance and operating procedures early during the design process will help in revealing safety problems at a time when corrective action can be taken at minimum cost.

In the engineering design, development, and fabrication process there are some seldom used techniques available that help to insure against unwelcome, and sometimes very costly surprises during final assembly and testing. One of these techniques involves the preparation of assembly, testing, and operational procedures concurrently with the design process. This is difficult due to the fact that the design details are just being formulated and are highly subject to change; nevertheless, the value of looking ahead to identify assembly methods and potential operational problems can prove to be vital. Just such an occurrence transpired during a large (and costly) missile system development program in the late 1950's. In this case there was a misunderstanding between two of the major design groups regarding the system design requirements. The mechanical group had provided the capability for operation of the system in any one of three modes, but the electrical group's design allowed for only one mode of operation. This did not become apparent until very late in the program when two engineers from the mechanical group were assigned to prepare overall system checkout and test procedures. What they found was that the system could only be operated in a fully automatic mode; the capability of operating the system in semi-automatic or manual mode was impossible. This was a very embarrassing turn of events for the contractor, and it undoubtedly did considerable damage to their reputation with the customer. This could all have been circumvented had the preparation of test and checkout procedures been initiated early, and continuously updated throughout the design process.

Another technique that costs little in expended effort or expense, but offers great advantage in certain situations during design and development programs, is the use of simple models. Inexpensive models can be developed to answer problems associated with assembly of complicated parts, to evaluate the feasibility of certain operations, and to provide a visual conception of size related to function. A good example of this occurred during a large missile emplacement program in the 1960's. A problem arose when a contractor, who was installing propellant piping, stated that he could not get a large section (approximately 20 feet long, and having a complex configuration) of the piping into the missile silo. The propellant piping was loaded into the silo by crane through a passageway on the side of the silo. The propellant piping was fabricated in California; then cleaned and sealed under a low blanket pressure, and shipped to various sites around the US. Thus, it would have been very costly to redesign and fabricate replacement pipe sections. The assessment of the contractor was subsequently challenged by the customer after consulting his propellant system consultant for advice. Fortunately, there was a civil engineer in the consultant group who recommended that a model be constructed to determine whether it was possible to rig the section of piping so that it could pass through the passageway. With considerable doubt about the possibility of answering a question involving such minute measurements with an inexpensive model replicating such a large structure, the propellant consultant worked with the civil engineer and constructed a model of the silo and passageway from cardboard. The piping section was modeled using a wire pipe cleaner. Sure enough, the model verified that the piping section could not be passed into the silo through the passageway when rigged as the contractor had proposed. However, when rotated 180 degrees, and rigged so that the opposite end of the piping section entered the silo first, the model piping section would just clear the passageway, and slip into the silo.

Prevention through design (PtD) is a process or concept used to prevent and control occupational injuries, illnesses, and fatalities or reduce workplace safety risks lessens workers' reliance on personal protective equipment [37]. In other words, PtD is a process of integration of hazard analysis and risk assessment methods early in the design and engineering stages and subsequently taking the actions necessary so that risks of injury or damage are prevented.

1.3 Prevention through Design (PtD)

Several national organizations have partnered with NIOSH in promoting this concept of recognizing the hazards of each industry and designing more effective prevention measures. These national organizations are: American Industrial Hygiene Association, the American Society of Safety Engineers, the Center to Protect Workers' Rights, Kaiser Permanente, Liberty Mutual, the National Safety Council, the Occupational Safety and Health Administration, ORC Worldwide, and the Regenstrief Center for Healthcare Engineering.

Work-related injuries are real, devastating, and common. Recent studies indicated that each year in the U.S., 55,000 people die from work-related injuries and diseases, 294,000 are made sick, and 3.8 million are injured. Yearly direct and indirect costs have been estimated to range from $128 billion to $155 billion. Most recent studies in Australia indicate that design is a significant contributor in 37% of work-related fatalities; hence, the successful implementation of prevention through design concepts can have substantial impacts on worker health and safety [38].

The concept of Prevention through Design can be defined as:

"Addressing occupational safety and health needs in the design process to prevent or minimize the work-related hazards and risks associated with the construction, manufacture, use, maintenance, and disposal of facilities, materials, and equipment." [39].

Today, many business leaders are recognizing PtD as a cost-effective means to enhance occupational safety and health therefore openly supporting PtD process to developed management practices to implement them. Besides the United States of America many other countries are actively promoting PtD concepts as well. For example, in 1994, the United Kingdom began requiring construction companies, project owners, and architects to address safety and health issues during the design phase of projects, and companies there have responded with positive changes in management practices to comply with the regulations. Also Australia developed the Australian National OHS Strategy 2002–2012, which put "eliminating hazards at the design stage" as one of five national priorities. Consequently, the Australian Safety and Compensation Council (ASCC) developed the Safe Design National Strategy and Action Plans for Australia encompassing a wide range of design areas including buildings and structures, work environments, materials, and plant (machinery and equipment) [39].

The goal of PtD, is to reduce the risk of occupational injury and illness by integrating decisions affecting safety and health in all stages of the design process. To move toward fulfillment of this mission, John Howard, M.D., 2002-08 director of NIOSH, said, "One important area of emphasis will be to examine ways to create a demand for graduates of business, architecture and engineering schools to have basic knowledge in occupational health and safety principles and concepts." [40]

Although PtD initiative focuses on design, one should realize the importance of other factors, such as behavior, management, leadership, and personal protective equipment. These factors may interact directly with designs that address occupational safety and health [41].

1.3.1 PtD Program Mission [42]

The mission of the Prevention through Design National initiative is to prevent or reduce occupational injuries, illnesses, and fatalities through the inclusion of prevention considerations in all designs that impact workers. The mission can be achieved by:

- Eliminating hazards and controlling risks to workers to an acceptable level "at the source" or as early as possible in the life cycle of items or workplaces.
- Including design, redesign and retrofit of new and existing work premises, structures, tools, facilities, equipment, machinery, products, substances, work processes and the organization of work.
- Enhancing the work environment through the inclusion of prevention methods in all designs that impact workers and others on the premises. The program strives to fulfill its mission through the following principles:

- High-Quality Research: NIOSH will continually strive for high quality research and prevention activities that will lead to reductions in occupational injuries and illnesses among workers in the Prevention through Design cross-sector.
- Practical Solutions: The NIOSH program for the Prevention through Design cross-sector is committed to the development of practical solutions to the complex problems that cause occupational diseases, injuries, and fatalities among workers in this sector. One source of practical recommendations is the NIOSH Health Hazard Evaluations (HHE) program. NIOSH conducts HHEs at individual worksites to find out whether there are health hazards to employees caused by exposures or conditions in the workplace.
- Partnerships: We recognize that collaborative efforts in partnership with labor, industry, government, and other stakeholders are usually the best means of achieving successful outcomes. Fostering these partnerships is a cornerstone of the NIOSH program for the Prevention through Design cross-sector.
- Research to Practice: We believe that our research only realizes its true value when put into practice. Every research project within the NIOSH program for the Prevention through Design cross-sector formulates a strategy to promote the transfer and translation of research findings into prevention practices and products that will be adopted in the workplace.

1.3.2 PtD Process

Figure 1.6 shows the PtD process to prevent and control occupational injuries, illnesses, and fatalities. As shown in the figure, stakeholders whose input is needed in PtD process are: Agriculture, Forestry, Fishing, Healthcare and Social Assistance, Mining, Services, Construction, Manufacturing, Wholesale, Retail Trade, Transportation, Warehousing, Utilities. Figure 1.7 shows (PtD) process flow chart [41].

1.3.3 Stakeholder Input

The Plan, developed from stakeholder input, focuses on eliminating hazards and minimizing risks in all designs affecting workers (more information on

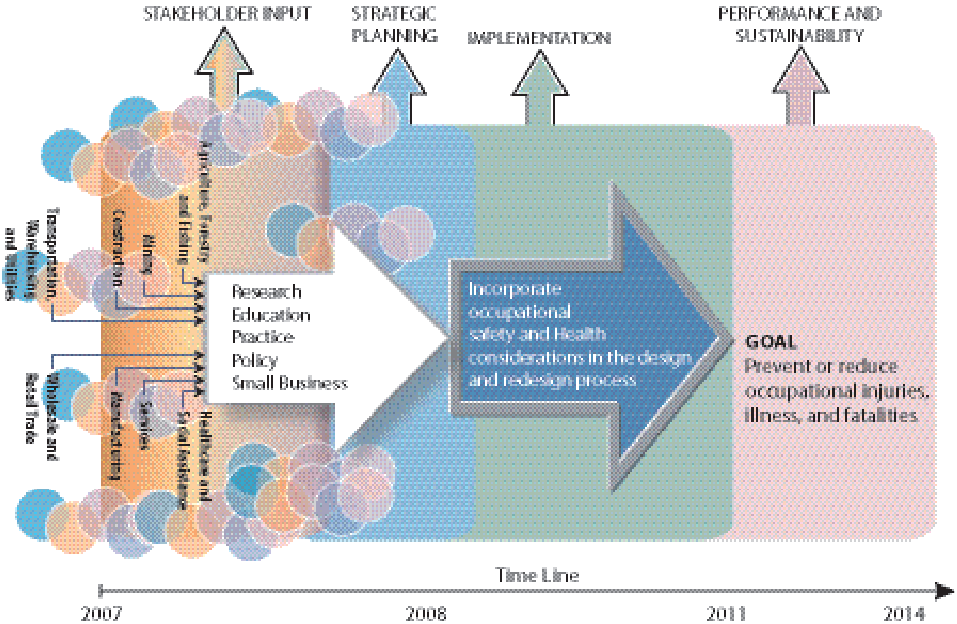


Figure 1.6 Approach to develop and implement the PtD National Initiative process (redrawn from Schulte & Heidel [43]).

the plan developed from stakeholder input is available on the NIOSH Web site). Work on the Plan was initiated at the first PtD Workshop in Washington, DC on July 9–11, 2007. Two hundred fifty stakeholders/workshop participants from all industry sectors including representatives from labor, industry, academia, and government discussed the most compelling issues to be included in this plan. As Figure 1.6 depicts, NIOSH is now in the Implementation phase of the PtD Plan.

Figure 1.8 shows examples of Prevention through Design in each sector [43]. For example Figure 1.8(4) shows how to prevent injury through effective design. Hazards associated with lifting cause significant risk to health care workers in the United States. Studies showed that, in 2003 alone, caregivers suffered 211,000 occupational injuries. As the population ages and the demand for skilled care services continues to increase, the occurrences of musculoskeletal injuries to the back, shoulder, and upper extremities of caregivers will also increase [43]. Mechanical lifting devices such as shown in this figure reduce risk of back injuries to health care workers and improve patient safety and comfort.

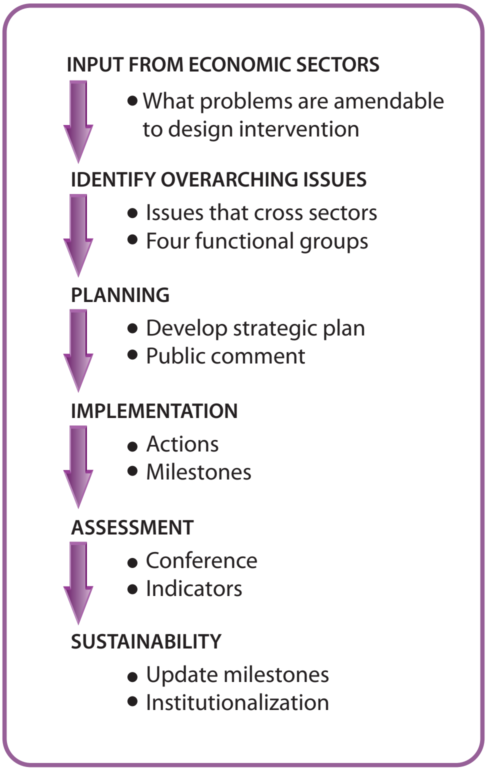


Figure 1.7 Prevention through Design (PtD) process flow chart [41].

Agriculture ranks fourth in the United States for work-related fatalities [44]. In general, fatalities associated with agricultural machinery involve farm tractors, and rollover incidents. As shown in Figure 1.8(1) death and injuries can be prevented with built in rollover protection.

Sharps include needles, syringes, razor blades, slides, scalpels, pipettes, broken plastic, glassware, and other objects capable of cutting or piercing the skin [45]. Sharps injuries and infectious diseases can occur in all aspects of clinical and operating room (OR) duties. Thinking loudly, “no needle, no risk.” Unfortunately, this is not possible in all healthcare settings. However, infectious diseases in healthcare workers can be prevented through safer sharps design (Figure 1.8(3)).

Healthcare workers may experience musculoskeletal disorders (MSDs) at a rate exceeding that of workers in construction, mining, and manufactur-

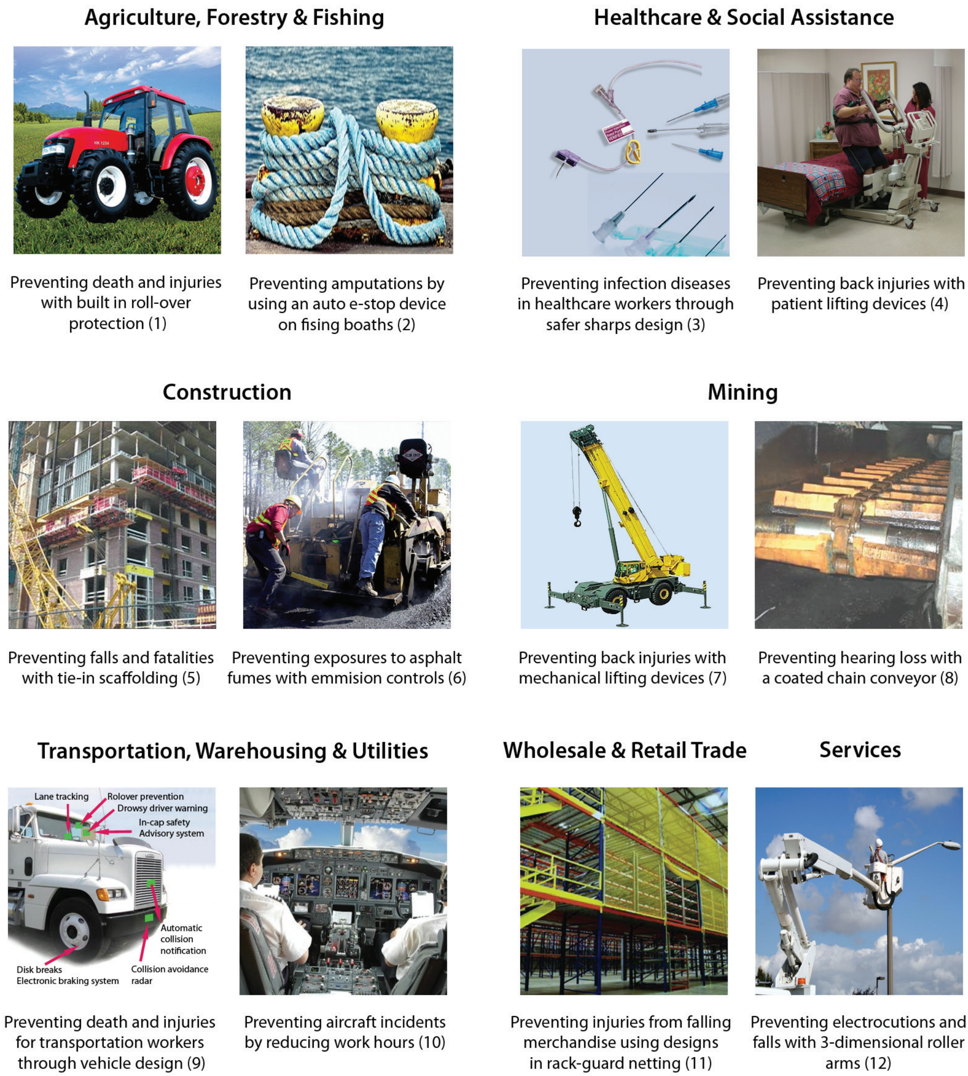


Figure 1.8 Examples of Prevention through Design (PtD) in each sector (adapted from Schulte & Heidel [7], pictures were taken from internet).

ing [46]. These injuries are often involving heavy manual lifting associated with transferring, and repositioning patients. According to the United States Department of Labor Occupational Safety and Health Administration, “Back disorders are the leading cause of disability for people in their working years.” As shown in Figure 1.8(4), back injuries can be prevented by properly designed patient lifting devices.

Falls from scaffolding are the most frequent cause of very serious injuries, including spinal cord injury, brain injury, and wrongful death. As shown in Figure 1.8(5) by designing Scaffolds with proper guardrails and toe boards, falls and fatalities can be prevented.

As shown in Figure 1.8(6), over a half-million workers are exposed to fumes from asphalt, a petroleum product having applications extensively in road paving, roofing, siding, and concrete work. Health hazards that can affect workers from exposure to asphalt fumes include headache, skin rash, sensitization, fatigue, reduced appetite, throat and eye irritation, coughing, and skin cancer. With emission controls exposures to asphalt fumes can be prevented.

Exposure to loud noises is one of the most common causes of hearing loss. Exposure to noise level above 85 decibels can damage hearing. The noise from power lawn mowers, tractors and hand drills are in the noise level of 90- to 98-decibel range. If workers are regularly exposed, for a minute or longer, to bulldozers, chain saws, ambulance sirens or jet engine takeoffs, they are at risk to damage their hearing. Recent studies showed that 30 million people are at risk in the workplace, in recreational settings, and at home. Hearing loss is the most common work-related disease. For example, as shown in Figure 1.8(8), applying coatings on a noisy chain conveyor can prevent hearing loss.

1.3.4 Strategic Goal Areas

As shown in Figure 1.9, the PtD National Initiative is organized around four functional areas: research, practice, education and policy. Small Business was added as an additional focus area for goal development to address the challenges of applying PtD methods to small business processes and envi-

PtD Strategic Goals

RESEARCH	Research will establish the value of adopted PtD interventions, address existing design-related challenges, and suggest areas for future research.
EDUCATION	Designers, engineers, health and safety professionals, business leaders, and workers understand PtD principles and apply their knowledge and skills to the design of facilities, processes, equipment, tools, and organization of work
PRACTICE	Stakeholders access, share and apply successful PtD practices.
POLICY	Business leaders, labor, academics, government entities, and standarddeveloping and setting organizations endorse a culture that includes PtD principles in all designs affecting workers.
SMALL BUSINESS	Small businesses have access to PtD resources that are designed for or adapted to the small business environment

Table 1.9 PtD Strategic goals for functional areas [41].

ronments. Detail discussions of these functional areas for eight sectors are given in references [47, 48, 49, 50, 51, 52, 53, 54].

The expected result of PtD is: Prevent or Reduce occupational injuries, illnesses, and fatalities through these functional areas. Each of these functional areas is supported by a strategic goal. A summary of the strategic goals for each of these areas is given in Figure 1.9 [43].

Research: Prevention through Design research is central to the National Institute for Occupational Safety and Health's (NIOSH) national PtD initiative. Research is required to support PtD efforts in all of the other three functional areas (Practice, Policy, and Education) and within all eight-stakeholder sectors. Research will provide the opportunity to explore and gain further understanding of the PtD concept, and evidence to support a national PtD initiative [55]. The research should consider performance not only on worker safety and health, but also on other prospects such as cost, quality, and sustainability.

Education: Education is one of the important activities of the Prevention through Design (PtD) initiative. It is a major factor required to make PtD successful. Development of PtD knowledge and skills can occur through enhanced design and engineering curricula as well as through improved professional accreditation programs that value PtD issues and include them in their performance evaluation and competency assessments. The educational requirements can be different within each sector. Therefore, an education strategy should be developed with an overall approach and set of resources, which is then customized to each sector [43, 56].

The main themes of the PtD Education Functional Area are [56]:

- Classify every education action as developing awareness or capability
- Develop education resource materials that are available to all
- Tailor approach and resources to each of the constituents in a sector
- Incorporate elements for all size companies
- Conduct assessment and continuous improvement efforts
- Identify drivers of education change and work with them

Although stakeholders recognize the need to incorporate the PtD concept in engineering course content, currently, most of the curricula of the various engineering disciplines don't include the tools and techniques needed for utilizing PtD concepts. The National Institute for Occupational Safety and Health (NIOSH) has a project to diffuse PtD principles into engineering textbooks as they are being written or revised for new editions.

Prictice: There are numerous examples of PtD that exemplify current business practices. These examples implementing PtD concepts should be promoted to other businesses as being a good way to enhance their performance and improve their outcome. Products that are developed with PtD concepts in mind can become a good advertising point. Practice also should include the value of workers' health and safety in design decisions and exploring relations with the movements toward green and sustainable design [43, 57].

Policy: The Policy Functional Area of Prevention through Design concept includes internal and external initiatives that are planned to integrate PtD into business and governmental organizations. Research areas of PtD will determine what works best, practice will develop tools and implementation plans, and education will teach those who can implement PtD. PtD functional areas are not separated by clear and distinct boundaries. Instead there is significant overlap and interdependence among them [58].

"Policy focuses on creating demand for safe designs for workers and incorporating these safety and health considerations into guidance, regulations, recommendations, operating procedures, and standards [43]".

Small Business: Many large retailers have successful safety policies and programs in position. Simplified version of such policies should be promoted to other businesses, and adapted as necessary to meet the unique needs of small businesses.

1.3.5 The Business Value of Prevention through Design

Annually 5,800 people die from work-related injuries and diseases, 228,000 become ill, and 3.9 million are injured in the United States [59]. Each year direct and indirect costs of work-related injuries, illnesses, and fatalities have been estimated to range from $128 billion to $155 billion [41]. Recent studies reveal that the successful implementation of PtD concepts can greatly improve worker health and safety and reduce the work-related fatalities. Hence, translating to lower workers' compensation expenses.

In the "business case" for Industrial Hygiene (IH) study, a strategy that enables IH professionals to qualitatively and quantitatively analyze the business value of IH activities and programs was developed and tested [60]. The study findings showed that considerable business costs savings are associated with hazard elimination and the application of engineering controls to minimize risks [43]. Occupational hygiene programs or hazard control measures will provide a return on the investment in the form of financial or other benefits.

Figure 1.10 illustrates Prevention through Design using a hierarchy of controls. As shown in this figure, if one selects hazard control measures higher in the hierarchy of controls, the value to the business increases. Prevention Through Design is a concept or process that starts with identifying the hazard(s) and then eliminates the hazard(s) hence reducing the risk to an acceptable level by applying the hierarchy of controls shown in Figure 1.10. Elimination of potential sources of hazard(s) ranks highest in the hierarchy

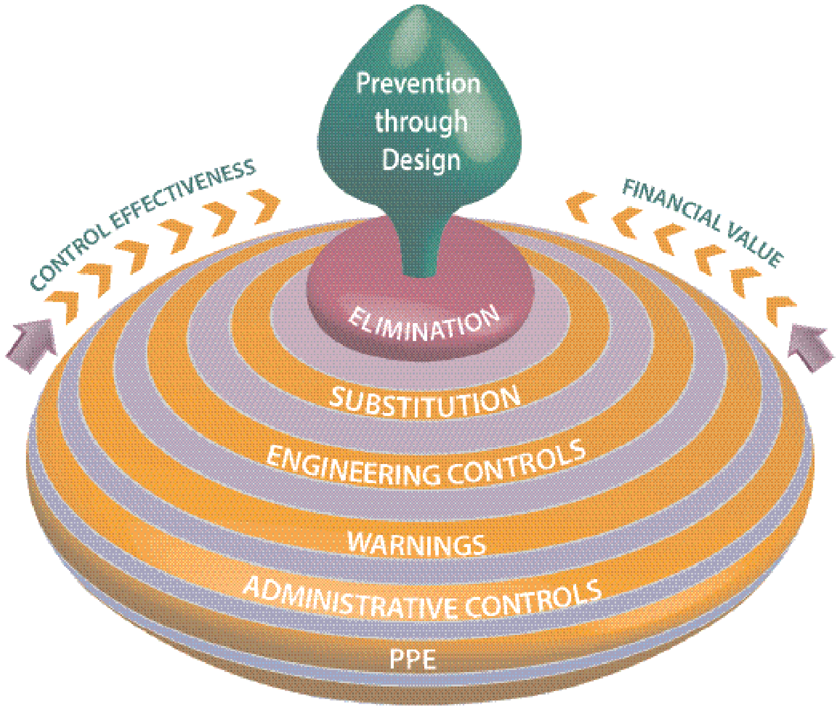


Figure 1.10 Prevention through Design using hierarchy of controls (redrawn from Schulte & Heidel [43]).

of controls. Followed by substitution, engineering controls and warnings in the hierarchy of controls.

Administrative controls are required work practices and policies that prevent hazard(s) and reduced risk. Administrative controls rank low in the hierarchy of controls because their effectiveness depends on consistent implementation by management and personnel. Personal Protective Equipment (PPE) is the last line of defense and ranks lowest in the hierarchy of controls. The time to control hazards should be considered during all stages of the design process for any project.

1.4 Case Studies

The following case studies demonstrate considerable business costs savings associated with hazard elimination and the application of engineering controls to minimize risks [61].

1.4.1 Case Study 1: [61]

Chemical Containment

Description of Operation

The operation where the intervention occurred is a process step in the manufacturing of active pharmaceutical ingredients, which were subsequently formulated in various drug products. The current operation was an open process involving the repack of resin columns using an acetonitrile (ACN) slurry.

Hazard Identification

The current operation involved the addition of ACN into an open manway of a process tank. During the operation two operators were exposed to levels of ACN ranging from 60-100 parts per million (PPM). Operators were required to wear powered air-purifying respiratory protective equipment to protect against airborne ACN exposures that were created during the solvent charging process.

Hazard Intervention

To reduce exposure, an engineering control consisting of purchasing and installing a high containment valve was implemented. By using the high containment valve for charging the tank, airborne exposures of ACN were virtually eliminated.

Impacts of the Intervention

Due to the installation of engineering controls, the airborne levels of ACN were reduced from the 60-100 PPM range to less than or equal to 1 PPM. The resultant exposure level eliminated the requirement for operators to wear respiratory protective equipment (RPE). As a result there was a cost savings associated with the elimination of the RPE as well as the associated time required to properly don/doff the RPE. Prior to the intervention the process step required three operators, which was subsequently reduced to two operators after the implementation of the containment project, thus significantly reducing overall labor costs associated with the operation.

Although no quality deviations had been previously associated with this manufacturing step, the containment and enclosure of the open process were also recognized as a quality control improvement. In addition, containing the process also eliminated foaming issues sometimes noted during the operation of the process, but the benefit of the reduction has yet to be fully evaluated.

The process change also reduced by one third the amount of ACN lost to the environment during the operation, thus allowing a small material savings and a corresponding lowering of volatile organic compound (VOC) air emissions. The enclosed process would require additional Leak Detection and Repair (LDAR) monitoring points to be added to the environmental monitoring schedule, but the incremental costs were minimal.

Another benefit of the project was the elimination of the need to dispose of used RPE as hazardous waste. As a result one drum of hazardous waste per month and the associated disposal costs were eliminated.

Financial Metrics

The financial metrics associated with the intervention indicated that the project yielded a 5-year net present value (NPV) of $23,629 with an internal rate of return of 14%. The project had a discounted payback period of 3.8 years. Therefore in addition to the benefits of lower employee ACN exposures, improved air quality, reduced air emissions and reduced hazardous waste the project also yielded a competitive rate of the return from the organization's investment. The project also resulted in some improvement in employee morale due to eliminating the need for the wearing of respiratory protective equipment.

Lessons Learned

The implementation of engineering controls resulted in a process change that reduced labor and material costs, improved product quality, reduced air emissions, and reduced the volume of hazardous waste generated and its associated disposal cost and liability.

1.4.2 Case Study 2: [61] Automated Baler

Description of Operation

The facility manufactures paper-packaging products. The intervention was performed on a waste paper baling operation.

Hazard Identification

The waste paper baling operation required that three operators spend approximately 30 minutes at the end of each shift (three shifts per day) loading paper scrap into the existing manually-loaded scrap baler. The operation was labor-intensive with operators grabbing armfuls of shredded paper and cramming the scrap into the baler. The operation required awkward lifting, twisting, and posturing. An ergonomics risk assessment determined that, because of the various and continual ergonomic stresses present, the operation posed a high risk of causing a serious musculo-skeletal injury.

The facility had not experienced any ergonomic injuries associated with the baling operation but from past company experience the medical and disability costs associated with lumbar injuries averaged from $7,500 to $50,000 per injury.

Hazard Intervention

The company decided to eliminate the hazard by purchasing an automatic loading baler to fully replace the manual handling associated with managing the shredded paper scrap.

Impacts of the Intervention

The intervention completely eliminated the risks associated with the manual handling during the waste baling operation. The new baler takes waste directly from the packaging production equipment and automatically bales and stacks it. In addition to removing the ergonomic risks, the intervention eliminated the need for three operators to devote 30 minutes at the end of each of three daily shifts to hand-load scrap onto the old baler. The intervention also eliminated the need for operators to wear PPE for eye hazards and nuisance dust. From an operator morale viewpoint, the intervention eliminated an unpopular task that was frequently rotated among the 47 production workers at the facility.

In addition to the direct labor saving benefits, the automated baler also reduced the amount of paper dust generated during the scrap handling operation. This resulted in less paper dust being distributed throughout the site, requiring less facility-wide cleaning while saving labor time, and also contributing to a cleaner process and product. The reduction in dust buildup was considered by the property insurance provider to have lowered the facility's fire risk.

Financial Metrics
The 5-year net present value (NPV) of the project was -$1,385 using a discount rate of 8% and an inflation rate of 3%. The only costs included in the analysis were the labor savings from eliminating the need to manually load the baler and the capital cost of the baler purchase and installation. The costs associated with injury reduction, facility cleaning, and PPE elimination, were not included.

Lessons Learned
Although the project did not yield a sizable financial return on investment, the intervention did return the company's cost of capital while reducing a significant risk of injury due to manual handling. The project also illustrated that improvement in health and safety conditions often results in improved labor productivity. In this case, the positive benefits of the intervention were transferable to other facilities within the company thus serving as a best practice for the corporation.

1.4.3 Case Study 3: [61]
Carbon Monoxide Control

Background

The following case study involves a company with operations in industrial manufacturing. The case study will focus on a heat-treating facility. The process entailed open-room exhaust of natural gas-fired furnaces and open-room exhaust of endogas (a carbon rich atmosphere used in heat-treating furnaces). Once exhausted to the room, the only ventilation was achieved through axial roof fans.

Hazard Identification

The hazard identified with this particular industrial manufacturing operation involved carbon monoxide (CO) exposure to employees working within a heat-treating facility. CO is a poisonous gas that is odorless, colorless, and tasteless. Carbon monoxide is harmful when inhaled because it displaces oxygen in the blood and deprives vital organs such as the heart and brain from receiving oxygen. CO poisoning can be reversed if caught in time, but even with recovery, acute poisoning may cause permanent damage. OSHA standards prohibit worker exposure to more than 50 parts per million (ppm) over an 8-hour time-weighted average (TWA).

Hazard Intervention

The company identified the hazard as a chemical exposure to employees. The abatement approach involved a change in the administrative and engineering controls. Data points for CO were routinely collected and administrative controls were implemented as necessary. The corporate goal for CO levels was less than half of the TLV for CO (12.5 ppm). This goal was reached by implementing local exhaust ventilation (LEV) as the primary engineering control. All CO emission points (burner exhausts and endogas exhausts) were identified and targeted for LEV source controls. A ventilation system with variable-speed fans controlled by real-time direct reading electrochemical sensors for CO was installed in the heat-treating facility.

Impacts of the Intervention

There were many positive health, business, and risk management results from the implementation of the engineering controls. Health improvements resulted from the intervention because employees were not directly exposed to CO. Employees were healthier, happier, and more comfortable in the workplace. Health-related absenteeism was reduced drastically. Employee morale increased significantly, improving the quality of the work. The business process was improved because there was a reduction of CO concentration in the heat treat.

While this project did not demonstrate a significant financial payback, many benefits resulted from it. The project demonstrated the leadership commitment to HSE. A major facility aesthetic improvement resulted because all of the smoke and haze were properly exhausted through the LEV system under a state-permitted emission source. There were no changes in product quality or customer satisfaction or service resulting from the intervention.

Financial Metrics

The project's capital requirements were $1.6 million to install the ventilation system. The intervention resulted in a negative net present value (NPV) of -$1,005,597. The internal Rate of Return (IRR) was -25% while the return on investment (ROI) was -56%. Utility costs associated with running the IH-related equipment were expected to increase once the intervention was in place.

Lessons Learned

Retrospective analyses do not provide the opportunity to evaluate the costs and benefits of alternative hazard control solutions, but even in negative cost situations IH value can be demonstrated. In this case, the heat-treat operation was an ultimate financial negative but a health, morale, and productivity positive. The benefits were valuable to management, and in time will very likely shown to have financial payback as well.

1.4.4 Case Study 4: [61]

Metal Removal Fluid Management Control Plan

Description of Operation

The following case study involves a company with operations in auto manufacturing. The process involved an automotive transmission machining plant for a global transportation company. This case study focuses on a machining department where metal removal fluids (MRF) such as lubricants and coolants are utilized in production processes.

Hazard Identification

The hazard identified with this particular equipment manufacturing operation involved employee exposure to contaminated metal removal fluids in the automotive transmission machining plant. In 2002, an employee reported to the plant medical department with complaints of respiratory illness while working in machining plant. The employee was working in a machining department where metal removal fluids (MRF) such as lubricants and coolants were utilized in production processes.

A subsequent medical examination confirmed that the employee was diagnosed with occupational hypersensitivity pneumonitis (HP). The employee received medical treatment, was placed on medical leave, and an investigation of the cause of the disease was undertaken. Hypersensitivity pneumonitis is a serious lung disease associated with exposure to microbiologically-contaminated aerosols of some synthetic, semi-synthetic and soluble oil metalworking fluids. In the short term, HP is characterized by coughing, shortness of breath, and flu-like symptoms (fevers, chills, muscle aches, and fatigue). The chronic phase (following repeated exposures) is characterized by lung scarring associated with permanent lung disease.

Hazard Intervention

The company identified the hazard as microbiological contamination of the metal removal fluid. The abatement approach was to change the type of fluid in use and implement a comprehensive MRF Control Plan that provided for proper selection of metal removal fluids, development of efficient coolant and machine maintenance schedules, and design of effective ventilation systems to maximize control of coolant aerosols.

The initial study and completion of IH risk assessments did not identify a clear relationship between known air contaminants in the work environment and the respiratory disease. Therefore a multifunctional task force was created, with the primary objective to eliminate the risk of respiratory disease (HP) associated with metal removal fluid (MRF). The task force had represention from the following groups: division and plant functions, corporate/plant IH, corporate research and development IH, plant union S&H and IH, division/plant medical, corporate/plant environmental engineering and chemical management, plant manufacturing leadership, manufacturing engineering, and maintenance. The task force conducted numerous exposure assessments, research studies, production process changes, and maintenance process improvements.

Impacts of the Intervention

There were many positive health, business, and risk management benefits that resulted from the implementation of the comprehensive MRF Control Plan. Health improvements resulted from the intervention because the air contaminant exposure associated with MRF machining was eliminated or reduced and employees were no longer directly exposed. No further cases of HP have been reported in the four years following the intervention. Employee respiratory complaints were eliminated or reduced. Employees were healthier, happier, and more comfortable in the workplace. Employee morale increased significantly, improving the trust and confidence of employees in the S&H program.

The business process was improved as tooling life was extended and therefore tooling costs were reduced. Many risk management benefits resulted from the intervention, including enhanced relationships between the division and plant union management. Management and engineering systems to support MRF S&H goals were enhanced. Another benefit involved the development of improved bio-stable coolant strategies.

Financial Metrics

As part of the value study, a retrospective analysis was conducted with an incremental approach to reduce workplace illnesses, and improve the risk management and business processes. After using the Value Study Data Collection Tool and entering the data in the ROHSEI software, the net present value (NPV) for the project was calculated for a project length of 5 years, resulting in $991,888 NPV. The internal rate of return (IRR) was 120%, while the return on investment (ROI) was 22%. The discounted payback period (DPP) was 0.5 years. Total costs after reducing, mitigating, or controlling the IH hazards were $2,883,573.

Management also realized that their efforts to reduce employee exposures to air contaminants from metal removal fluids through a comprehensive MRF Control Plan needed to continue on a regular basis.

Lessons Learned

Without IH involvement in this problem, it would have been difficult to identify the source of the hazard because the relationship between illness and MRF is not well understood. With experience investigating complaints of this nature, IH was able to pinpoint the microbiological nature of the hazard and make recommendations that solved the problem.

Ultimately, the task force concluded that an effective MRF Management Program is essential for ensuring the health and safety of employees working in aluminum and iron metal machining operations.

1.5 Prevention through Design and Sustainability

The concepts of sustainability and PtD were identified as very congruent and able to co-exist [62]. Prevention through Design linked to sustainability in many ways. Sustainability refers to accepting a duty to seek harmony with other people and with nature. Sustainability is not just about the environment. It is sharing with each other and caring for the Earth.

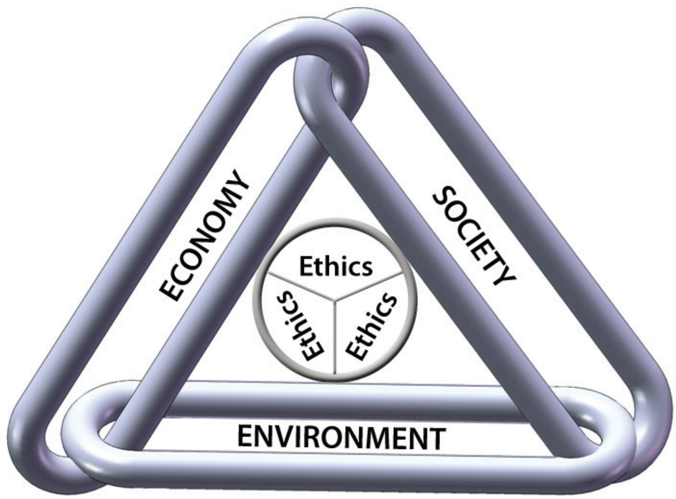


Figure 1.11 Sustainability and interconnectivity of environment, economy and society.

Figure 1.11 shows Interconnectivity of environment, economy and society. As shown in this figure, sustainability is a multidimensional concept, involving environmental equity, economic equity and social equity. Therefore, an appropriate measurement framework should cover the economic, social and environmental dimensions of sustainable development. As shown in this figure, ethics are the building blocks of sustainable development and should be incorporated into design development strategy to ensure long-term sustainability.

For example, a sustainable building project must not result in undesirable harm to the environment during its construction and use. The building must also make economic wisdom such that, over the long term, the revenues will at least equal the expenses of constructing and operating it. Finally, the building must be socially acceptable such that the building will not cause any harm to any person or causes a group of people to experience injustice. What could be more unreasonable than to have workers construct a building that is not as safe to build as it could be? That is to say, isn't it fair to design a building to be safe as much as possible. A fair construction project is when the designers have made reasonable effort to "design out" or minimize hazards and risks early in the design process. Sustainable construction occurs when design contributes to safety [63].

The engineering profession is being challenged with a new and forceful set of requirements, which appear about to happen: population growth, resource scarcity, and environmental change. For example, these include apparent changes to the atmosphere, hydrosphere, and biosphere resulting in major shifts from the environmental norms under which the artifacts of our civilization were originally designed. At one time, these aspects of the engineering design could be taken for granted, because of the obvious stability of the environment within a narrow, acceptable, and predictable range of change. Including the added interconnectivity and complexity of the environment, shifting requirements from environmental changes will not be easily addressed with methods descended from our industrial age.

1.5.1 Transdisciplinary Sustainable Development

Figure 1.12 shows one widely accepted concept of sustainable development—interconnectivity of environment, economy and society. The environment plays an important role in the well being of community development. It affects a broad range of social and economic variables which have a vital impact on the quality of community life, human health and safety. A dynamic environment contributes to a healthier society and a more strong

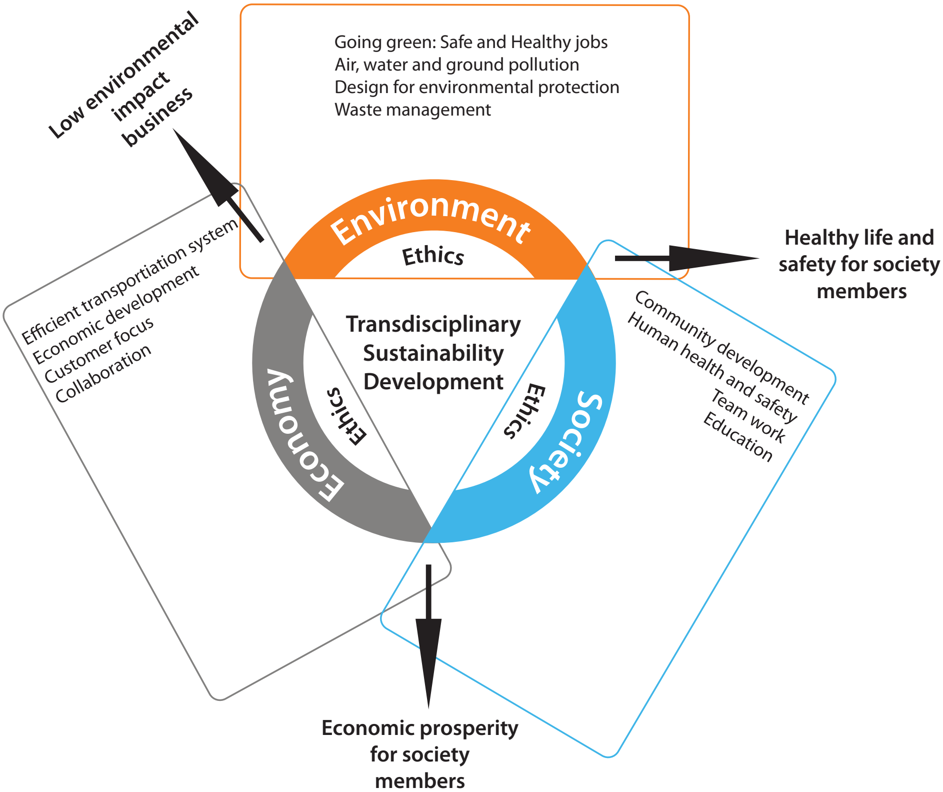


Figure 1.12 Transdisciplinary sustainable development.

economy. Similarly, the environment is itself affected by economic and social factors.

Traditional development was strongly related to economic growth, which provides economic prosperity for society members. During the early 1960s, the growing numbers of poor in developing countries resulted in considerable attempts to improve income distribution to the poor. As a result, the development paradigm changed towards equitable growth, where social (distributional) objectives, especially poverty alleviation, were accepted to be as important as economic efficiency. By the early 1980s, clear evidences proved that environmental degradation was a major barrier to development. Hence, protection of the environment became the third major element of sustainable development [64].

1.5.2 Contaminated Environment [65]

Over increasingly large areas of the United States, spring now comes unheralded by the return of the birds, and the early mornings are strangely silent where once they were filled with the beauty of bird song.

Rachel Carson

Rachel Carson combined her interests in biology and writing as a government scientist with the Fish and Wildlife Service in Washington, D.C. Her book entitled "Silent Spring" is credited with inspiring much of the late 20th century's environmental concern as she documented the effect of pesticides on the ecology.

These sprays, dusts, and aerosols are now applied almost universally to farms, gardens, forests, and homes-nonselective chemicals that have the power to kill every insect, the "good" and the "bad," to still the song of birds and the leaping of fish in the streams, to coat the leaves with a deadly film, and to linger on in soil-all this though the intended target may be only a few weeds or insects. Can anyone believe it is possible to lay down such a barrage of poisons on the surface of the earth without making it unfit for all life? They should not be called "insecticides," but "biocides."

Rachel Carson

The condition of the environment and what can be done to protect it in the future ranks high among the concerns of Americans in the twenty-first century. The degradation in the environment that has occurred during the intervening years make it devastatingly clear that continued growth in population and economical development make the correction of past ecological misuse complex and expensive. Hazardous substances at uncontrolled hazardous waste sites including chemicals, pesticides, heavy metals and other toxic substances from industrial processes, refueling facilities and agriculture have been seeping into the ground and aquifer for many years. Scientists and engineers must begin to recognize the delicate nature of the environment in their endeavors and give it the priority it deserves.

Air Pollution

The quality of the layer of air that surrounds the earth has been degraded to the extent that warnings are issued in many cities when contamination levels reach the hazard zone. Joggers are warned about jogging at times of the day when smog levels are elevated, and many metropolitan areas in the world have enacted motor vehicle and other industrial emission controls in an effort to lower air pollution levels. In Mexico City, more than 21 million people live in an atmosphere so foggy that the sun is obscured, so poisonous that school is sometimes delayed until late morning when the air clears. Air pollution can be prevented by lowering emissions levels from motor vehicles, and changing to more environmentally friendly commercial products. Factories that produce hazardous air pollution should use “scrubbers” or other procedures on their smokestacks to eliminate contaminants before they enter the air outside the plant.

Groundwater Contamination

Groundwater is one of the most essential natural resources and degradation of its quality has a major effect on the wellbeing of people. The quality of groundwater reflects inputs from the atmosphere, from soil and water-rock reactions, as well as from contaminant sources such as mining, land clearance, agriculture, acid precipitation and industrial wastes. The fairly slow movement of water through the ground means that dwelling times in groundwater is generally orders of magnitude longer than in surface water. Groundwater is an important water resource that serves as a source of drinking water for the majority of the people living in the United States. Contamination from natural and human sources can affect the use of these waters. For example, spilling, leaking, improper disposal, or accidental and intentional application of chemicals on the land surface will result in overspill that contaminates close-by streams and lakes.

Strong competition among users such as agriculture, industry, and domestic sectors is driving the groundwater table lower. The quality of groundwater is getting severely affected because of the extensive pollution of surface water. The sustainability of groundwater utilization must be assessed from a transdisciplinary perspective, where hydrology, ecology, geomorphology, and climatology play an important role.

Environmental problems are essentially research and development challenges of a different order. These problems can be solved by scientists and engineers working together with political entities that can enact the necessary legislation, obtain the required international cooperation, and provide the necessary funding. The environment can no longer be considered an infinite reservoir in which chemical discharges, toxic material dumping, and harmful stack vapors can be deposited based on the lack of a measurable deleterious effect on the immediate surroundings.

Managing the environment is an international problem that cannot be based on monitoring and controlling at the local level only. Engineers and scientists must play a key role in providing the essential technology for understanding these global problems and in implementing workable solutions.

1.5.3 Making Green Jobs Safe: Integrating Occupational Safety & Health into Green and Sustainability

In 2008 the world experienced the worst financial crisis of our generation, triggering the start of the most difficult recession since the Great Depression. The financial crisis has forced the policymakers to respond powerfully, creatively, and positively to severe financial crises: interest rates have been considerably reduced, stimulus package for green economy was signed, hundreds of billions of dollars have been provided to banking systems around the world. A stimulus package is planned to create or save up to 3.6 million jobs over the next two years, increase consumer spending, and stop the recession.

Barbier suggested that an investment of one percent of global Gross Domestic Product (GDP) over the next two years could provide the critical mass of green infrastructure needed to seed a significant greening of the global economy. "Green stimulus is well within the realm of the possible: at one percent of global GDP" [65, 66].

Although many elements of the green economy have value-added benefits for a global economy, we should retrain healthy consciousness of the potential hazards that workers face when performing Green jobs.

Schulte and Heidel stated that "There are benefits as well as challenges as we move to a green economy. Defined broadly, green jobs are jobs that help to improve the environment. These jobs also create opportunities to help battle a sagging economy and get people back to work. Yet, with the heightened attention on green jobs and environmental sustainability, it is important to make sure that worker safety and health are not overlooked. NIOSH and its partners are developing a framework to create awareness, provide guidance, and address occupational safety and health issues associated with green jobs and sustainability efforts, [67].”

Figure 1.13 shows that how our knowledge about old and new hazards intersects with challenges created by new technologies and adaptations of work activities to perform green jobs [67].

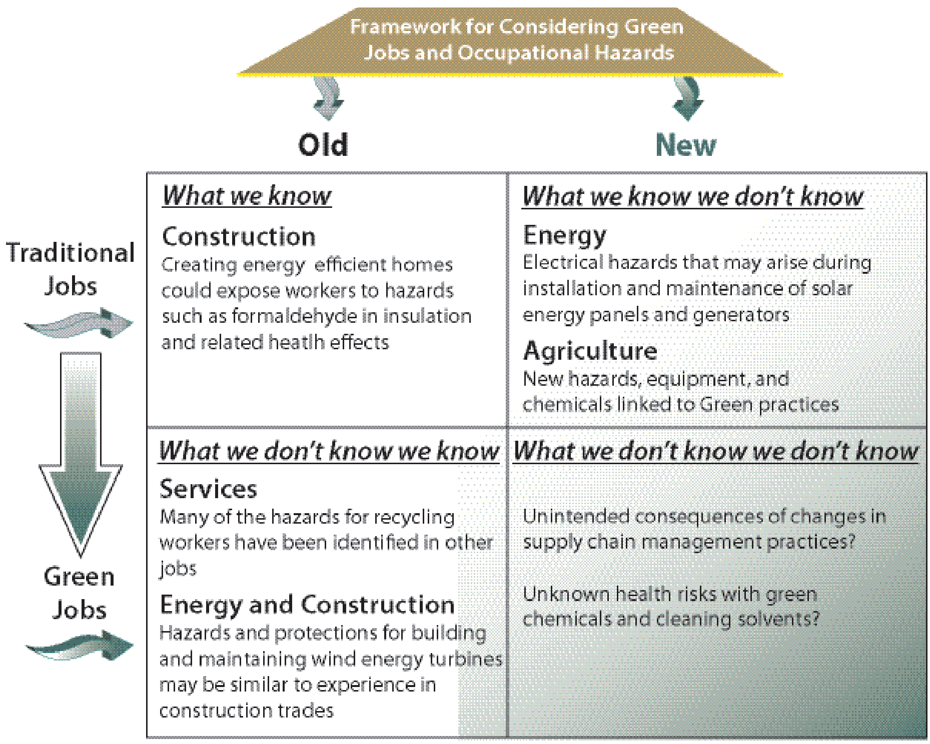


Figure 1.13 Framework for considering green jobs and occupational hazards.

Although many Green Job programs have the commendable goal of getting young workers into the workforce, it is known that these inexperienced new workers who could be the most at risk for job injuries. Moreover, in addition to these Green Job programs, stimulus package spending on infrastructure projects will also expose thousands of new workers to the myriad hazards encountered in the construction of bridges, highways, and public buildings. Hazards expected to be encountered in Green Jobs include [68]:

- Exposure to lead and asbestos in the course of energy efficiency retrofitting and weatherization in older buildings;
- Respiratory hazards from exposure to fiberglass and other materials in re-insulation projects;
- Exposure to biological hazards, such as molds, in fixing leaks;
- Crystalline silica exposure from fiber-cement materials, which may contain up to 50% silica;
- Ergonomic hazards from installation of large insulation panels;
- Fall hazards in the installation of heavy energy-efficient windows and solar panels and in the construction and maintenance of windmills (typically 265 feet tall);
- Electrical hazards encountered in the course of weatherization projects.

Green initiatives like recycling can have amazing successes. However, that doesn't automatically mean they are good for the earth, society or those working in 'green' jobs. For example more than 50 per cent of refined lead is now produced from recycled material. On the contrary, global lead production has increased considerably since 2003, placing a new generation at risk from an old and very toxic hazard.

As another example, Solar energy will play an essential role in meeting challenges such as human energy needs, address global warming, reduce U.S. dependence on energy imports, create "green jobs," and help revitalize the U.S. economy. However, as the solar PV sector expands, little attention is being paid to the possible environmental and health costs of that fast expansion. The most commonly used solar PV panels are based on materials and processes from the microelectronics industry and have the capability to create a huge new wave of electronic waste (e-waste) at the end of their useful lives. Recommendations to build a safe and sustainable solar energy industry include [69]:

- Reduce and eventually eliminate the use of toxic materials and develop environmentally sustainable practices,
- Ensure that solar PV manufacturers are responsible for the lifecycle impacts of their products through Extended,
- Producer Responsibility (EPR),
- Ensure proper testing of new and emerging materials and processes based on a precautionary approach,
- Expand recycling technology and design products for easy recycling,
- Promote high-quality "green jobs" that protect worker health and safety and provide a living wage throughout the global PV industry, including supply chains and end-of-life recycling,
- Protect community health and safety throughout the global PV industry, including supply chains and recycling.

1.5.4 Green During Construction

Green during the construction assures to the benefit of the surroundings community, workers and visitors on the site by reducing emissions, airborne pollution, and toxic gases like CO.

Green building development focuses on energy efficiency and using less toxic products from the perspective of future occupants of a building and also includes air quality issues such as, diesel exhaust generated by vehicles (which contains, nitrogen oxides, sulphur oxides and PAHs) in turn increases the risk of lung and perhaps bladder cancer. Also includes other health problems such as asthma and cardiovascular diseases. Similar problems can be expected from gasoline powered vehicles.

Dust is another issue in air quality. Dust consist of small solid particles created by a breakdown of fracture process, such as grinding, crushing or impact. Particles that are too large to stay airborne settle while others remain in the air indefinitely. General dust levels at considerably elevated concentrations may induce permanent changes to airways and loss of functional lung capacity.

Silica dust is accountable for a major American industrial disaster. Workers, number 300, die every year from silicosis, a chronic, disabling lung disease caused by the formation of nodules of scar tissue in the lungs. Hundreds more are disabled and between 3000 and 7000 new cases occur each year. Summarizing, high-risk work activities in construction are [66]:

- Chipping, drilling, crushing rock,
- Abrasive blasting,
- Sawing, drilling, grinding, concentrate and masonry and products containing silica,
- Demonstration of concrete/masonry,
- Removing paint and rust with power equipment,
- Dry sweeping of air blowing of concrete rock sand dust,
- Jack hammering on concrete, masonry and other surfaces.
-

Detail information on this subject can be found in reference [70].

1.6 Closure

It should be obvious that the material presented in this module constitutes only cursory treatment of the very broad and important subject of prevention occupational injuries, illnesses, and fatalities to anticipate and "design-out" or minimize hazards and risks when new equipment, processes, and business practices are developed. However, some understanding of the relative roles of the PtD is important; thus a brief concept description of the transdisciplinary PtD process has been included in this report. By examples, it has been shown that the Prevention through Design is a transdisciplinary process that involves many transnational and transcultural issues.

In this module, it has been shown that PtD is a shared concept crossing many diverse disciplines including; agriculture, forestry and fishing; construction;

health care and social assistance; manufacturing; mining; services; transportation, warehousing, and utilities; and wholesale and retail trade. A common research problem, which will be addressed by PtD associated with all the sectors from many different disciplines, is preventing and controlling occupational injuries, illnesses, and fatalities.

As the world becomes increasingly interconnected and multicultural, PtD process should consider synthesized tarnsdisciplinary, transcultural and transnational process models to facilitate culturally harmonious and capable prevention and control of occupational injuries, illnesses, and fatalities.

Some of the information in reference [20] Ertas, A. 2010. Transdisciplinarity: Design, Process and Sustainability. Transdisciplinary Journal of Engineering and Science. Vol. 1, No: 1, pp. 30-48. have been used in this module with TheATLAS permission.

1.7 References

1. Luszki M.B. 1958. Interdisciplinary Team Research: Methods and Problems. Vol. 3, Research Training Series, National Training Laboratories, National Education Association, New York University Press, New York, NY, p. 304.

2. Nicolescu, B., 2002. Manifesto of Transdisciplinarity. Translated from French by, K.C. Voss, State University of New York Press, Albany, NY, pp.43.

3. Stokols, D. 1998. The Future of Interdisciplinarity in the School of Social Ecology. School of Social Ecology, University of California, Irvine, CA. http//eee.uci.edu/98f/50990/readings.htm.

4. Upham, S. 2001. The Aims of Graduate Education, Keynote address to the Society for Design and Process Workshop on Global Transdisciplinary Education, Pasadena, CA.

5. Meilich, A. 2006. System of Systems (SoS) engineering & architecture challenges in a net centric environment. IEEE/SMC International Conference on System of Systems Engineering, pp.-5, ISBN: 1-4244-0188-7.

6. Pickett, J. P. 2000. American Heritage Dictionary of the English Language "Discipline", Boston: Houghton Mifflin.

7. Merriam-Webster Online Dictionary. 2009. Merriam-Webster Online. "Discipline".

8. Klein, J.T. 2004. Disciplinary origins and differences. Fenner Conference on the Environment: Understanding the population-environment debate: Bridging disciplinary divides. Canberra, AU pp.10 of 20. http://www.science.org.au/events/fenner/klein.htm.

9. Fowers B.J. 2008. From Continence to Virtue: Recovering Goodness, Character Unity, and Character Types for Positive Psychology. Theory & Psychology, Vol. 18, No. 5, 629-653.

10. Senge, P.M. 2006. The Fifth Discipline: The Art and Practice of the Learning Organization. Random House, Inc.

11. Merriam-Webster Online Dictionary. 2009. Merriam-Webster Online. Disciplinary.

12. The Carnegie Foundation for the Advancement of Teaching, 2008. About Us. http://www.carnegiefoundation.org/index.asp.

13. Sheppard, S.D., K. Macatangay, A. Colby, W.N. Sullivan. 2009. Educating Engineers, Designing for the Future of the Field. Carnegie Foundation for the Advancement of Teaching.

14. Petts, J., Owens, S. and Bulkeley, H. 2008. Crossing boundaries: interdisciplinarity in context of urban environments. Geoforum 39, pp. 593-601.

15. Karen, C. 2008. Transdisciplinary Research (TDR) and Sustainability Report. Ministry of Research, Science and Technology (MoRST), Environmental Science and Research, Ltd., NZ.

16. Ertas, A., Maxwell, T.T, Tanik, M.M. and Rainey, V. 2003. Transformation of Higher Education: The Transdisciplinary Approach in Engineering. IEEE Transactions on Education, IEEE Transactions on Education, Vol. 46, No:1, pp. 289-295.

17. Gumus, B. Ertas, A., Tate, D. and Cicek, I. 2008. The Transdisciplinary Product Development Lifecycle (TPDL) Model. Journal of Engineering Design, 19(03), pp. 185-200.

18. Tate, D. Maxwell, T.T., Ertas, A., Zhang,H-C., Flueckiger, P., Lawson, W., A. D. Fontent, A.D. 2010. Transdisciplinary Approaches for Teaching and Assessing Sustainable Design. International Journal of Engineering Education, Vol 26, No.2, pp.1-12.

19. Kollman T. and Ertas, A. 2010. Defining Transdisciplinarity. TheATLAS T3 Bi-Annual Meeting Proceedings. TheATLAS Publications, Vol-1, pp. 22-38.

20. Ertas, A. 2010. Transdisciplinarity: Design, Process and Sustainability. Transdisciplinary Journal of Engineering and Science. Vol. 1, No: 1, pp. 30-48.

21. Mittelstrass, J. 2003. Transdisziplinarität. wissenschaftliche Zukunft und institutionelle Wirklichkeit. ISBN 387940786X.

22. Transdisciplinary Training: Training the Next Generation of Researchers, Centers for Behavioral and Preventive Medicine. 2009. (http://www.lifespan.org/behavmed/TTURCTrainingNext.htm

23. Nicolescu, B. 2005. Toward Transdisciplinary Education and Learning. Science and Religion: Global Perspectives, pp. 1-12.

24. Hadorn, H. G., Susette Biber-Klemm, Walter Grossenbacher-Mansuy, Gertrude Hirsch Hadorn, Dominique Joye, Christian Pohl, Urs Wiesmann and Elisabeth Zemp. 2008. Handbook of Transdisciplinary Research, Enhancing Transdisciplinary Research: A Synthesis in Fifteen Propositions. Chapter 29, p. 435.

25. Peterson, L.C. and Martin, C. 2005. A New Paradigm in General Practice Research Towards Transdisciplinary Approaches. http://www.priory.com/fam/paradigm.htm.

26. Stokols, D., Harvey, R., Gress, J., Fuqua, J. and Phillips, K. 2004. In vivo Studies of Transdisciplinary Scientific Collaboration, Lessons Learned and Implications for Active Living Research. American Journal of Preventive Medicine, Volume 28, Issue 2, pp. 202-213.

27. Petts, J., Owens, S. and Bulkeley, H. 2008. Crossing boundaries: interdisciplinarity in context of urban environments. Geoforum 39. p. 597.

28. Green Energy Ohio. 2009. Danish Wind Industry Association. http://www.greenenergyohio.org/page.cfm?pageId=341.

29. Wind Turbine History, Alternative-Energy-Resources. 2009. http://www.alternative-energy-resources.net/wind-turbine-history.html.

30. PtD in Motion. February 5, 2008. National Institute for occupational Safety and Health (NIOSH).

31. Fisher J.M. 2008. Healthcare and Social Assistance Sector. Journal of Safety Research 39, pp. 179–181.

32. Paul A. Schulte, P.A., Rinehart, R., Okun, A., Geraci, C.L., Heidel, D.S. 2008. National Prevention through Design (PtD) Initiative. Journal of Safety Research 39, pp. 115–121.

33. Ertas, A and Jones, J. 1996. The Engineering Design Process. Second Edition, John Wiley & Sons, Inc., 1996.

34. DOE Standard, Integration of Safety into the Design Process, 2008. Report, DOE-STD-1189-2008, U.S. Department of Energy.

35. Gage, H. 1989. Integrating Safety and Health into M. E. Capstone Design Courses. ASEE, Southwest Regional Conf., Texas Tech University, Lubbock, TX.

36. Haddon, W. 1980. The Basic Strategies for Reducing Damage from Hazards of All Kinds. Hazard Prevention, Sept./Oct 1980.

37. Prevention through Design. 2009. National Institute for Occupational Safety and Health. http://www.cdc.gov/niosh/topics/ptd/.

38. Heidel, Donna S., Paul Schulte. 2008. Making the Business Case for Prevention through Design. NIOSH Science Blog, 6/2/08.

39. Prevention through Design. 2009. National Institute for Occupational Safety and Health. http://www.cdc.gov/niosh/topics/ptd/.

40. Prevention through Design. 2008. All Business, AD&B Company. http://www.allbusiness.com/labor-employment/workplace-health-safety/11715914-1.html.

41. Paul A. Schulte , Richard Rinehart, Andrea Okun, Charles L. Geraci, Donna S. Heidel, " National Prevention through Design (PtD) Initiative ," Journal of Safety Research 39, pp. 115–121, 2008.

42. Prevention through Design. 2008. National Institute for Occupational Safety and Health. http://www.cdc.gov/niosh/programs/ptdesign/.

43. Schulte, P., Heidel, D.S. 2009. Prevention through Design, in Motion, June 17.

44. Bell C, Stout N, Bender T, Conroy C, Crouse W, Myers J. 1990. Fatal occupational injuries in the United States. Journal of the American Medical Association. (50), pp. 263:3047.

45. Safety Note Number 8: Proper Handling and Disposal of Sharps. 1993. National Institutes of Health. http://www.niehs.nih.gov/odhsb/notes/note8.htm.

46. Preventing Back Injuries in Healthcare Settings. 2008. National Institute for Occupational Safety and Health. http://www.cdc.gov/niosh/blog/nsb092208_lifting.html.

47. Bealko, B.S., Kovalchik, G.P. and Matetic,J.R. 2008. Mining Sector. Journal of Safety Research, (39), pp. 187–189.

48. Behm, M.2008. Construction Sector. Journal of Safety Research, (39), 175–178.

49. Husberg, B. 2008. Agriculture, Forestry, and Fishing Sector. Journal of Safety Research, (39), pp. 171–173.

50. Fisher, M.J. 2008. Healthcare and Social Assistance Sector. Journal of Safety Research, (39), pp. 179–181.

51. Donna S. Heidel, S.D. 2008. Manufacturing Sector. Journal of Safety Research, (39), pp. 183–186.

52. Jeffrey V. Johnson, V.J. 2008. Services Sector. Journal of Safety Research, (39), pp. 191–194.

53. Madar, A.S. 2008. Transportation, Warehousing, and Utilities Sector. Journal of Safety Research, (39), pp. 195–197.

54. John W. Mroszczyk, W.J. 2008. Wholesale and Retail Trade Sector. Journal of Safety Research, (39), pp. 199–201.

55. Gambatese, A.J. 2008. Research Issues in Prevention through Design. Journal of Safety Research, (39), pp. 153–156.

56. Mann, AJ. 2008. Education Issues in Prevention through Design. Journal of Safety Research, (39), pp. 165–170.

57. Mei-Li Lin, M-L. 2008. Practice Issues in Prevention through Design. Journal of Safety Research, (39), pp. 157–159.

58. Jim Howe, J. 2008. Policy Issues in Prevention through Design. Journal of Safety Research, (39), pp. 161–163.

59. Injuries, Illnesses, and Fatalities. Industry Injury and Illness Data. 2006. Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics, Safety and Health Statistics Program, BLS.

60. Strategy to Demonstrate the Value of Industrial Hygiene. 2008. American Industrial Hygiene Association. http://www.aiha.org/votp/AIHA_4.html.

61. American Industrial Hygiene Association - IH Value. 2009. http://www.aiha.org/votp_NEW/index.html.

62. Michael Behm, "Construction Sector," Journal of Safety Research 39 (2008) 175–178.

63. Prevention through Design, design for Construction Safety. 2009. http://www.designforconstructionsafety.org/concept.shtml.

64. Munasinghe, M. 2007. Sustainomics and sustainable development. The Encyclopedia of Earth, May 7. http://www.eoearth.org/article/Sustainomics_and_sustainable_development.

65. Global Green New Deal, Pulicy Brief. 2009. Published by the United Nations Environment Programmeas part of its Green Economy Initiative in collaboration with a wide range of international partners and experts.

66. Edward B. Barbier, B.E. 2009. A Global Green New Deal. UNEP-DTIE, February 2009.

67. Schulte, P. and Heidel, S. 2009. Going Green: Safe and Healthy Jobs. PtD in Motion, Issue 5, July, 2009.

68. Green Jobs-Safe Jobs campaign. 2009. National Council for Occupational Safety and Health. http://coshnetwork6.mayfirst.org/node/133.

69. Toward a Just and Sustainable Solar Energy Industry.2009. Silicon Valley Toxics Coalition White Paper, January 14, 2009. www coshnetwork.org/node/266.

70. Celenza, J. 2009. Green During Construction Project. RI Committe on Occupational Safety and health.

TheATLAS
Publishing