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Industrial Engineers on their Current Practice: Implications for the Integration of Social and Technical Sub-Systems in Work System Design

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INDUSTRIAL ENGINEERS ON THEIR CURRENT PRACTICE: IMPLICATIONS FOR THE INTEGRATION OF SOCIAL AND TECHNICAL SUB-SYSTEMS IN WORK SYSTEM DESIGN

by

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A thesis presented to Ryerson University
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Master of Applied Science

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Abstract

Sub-optimal work system design results in ill-effects for individuals, businesses, and society. By improving the integration of social and technical systems in design by industrial engineers, work system outcomes could be improved. Semi-structured interviews were conducted with 19 Canadian industrial engineers. Data was transcribed, coded, and analyzed using an iterative, inductive process. Results showed that industrial engineering practice is diverse and is influenced by macro-, meso-, and mirco-level ecological factors. Stakeholder awareness of industrial engineering, management support and understanding, role clarity, organizational structure, and relationships between industrial engineers and management, system users, and ergonomists all influenced the effectiveness of industrial engineers. It was concluded that a systemic approach to changing the work system design process is most likely to be successful in establishing consistent, long-term improvement of work system outcomes and application of ergonomics. Further investigation of work system design practices from the perspective of management and system users is recommended.

Acknowledgments

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Finally, I would like to dedicate this thesis to Ling-Ling Hui for helping me through an immeasurable number of obstacles and catastrophes over the last few years. Thank you!

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Chapter 1
Introduction

The project ‘Work System Design: A Study of Professional Practices among Ergonomists and Engineers’ is a two phase study by the Human Factors Engineering Lab at Ryerson University. Using interviews, this study examines the roles and practices of Canadian industrial engineers and ergonomists in the design of safer, more productive workplaces. In particular, the project aims to foster better cooperation between industrial engineers and ergonomists and to better integrate ergonomics into the work system design process.

This thesis introduces the engineering interview phase of the project. By interviewing industrial engineers in Ontario whose work impacts work system design, the project will examine the day-to-day work of industrial engineers, as well as the unique constraints and demands placed on them when working on work system design related projects.

1.1 The effects of sub-optimal work system design

Poorly designed work systems have human, social, and business effects. The number of professionals (Badham & Ehn, 2000), tools and methods (Neumann et al., 2007) dedicated to improving the relationship between technological systems and human capabilities is increasing; however, the problem of workplace ill-health remains prevalent. In 2007, 973 462 Canadians filed claims with their provincial workers’ compensation board and 1055 Canadians lost their lives due to workplace illness or injury (Association of Workers' Compensation Boards of Canada, 2009).

At a societal level, the direct cost of workers’ compensation benefits totaled $9.6 billion nationally in 2007, with $4.3 billion distributed in Ontario alone (Association of Workers' Compensation Boards of Canada, 2009). It has been shown that the costs of musculoskeletal disorders in the United States is comparable to that of all cancers combined and substantially greater than costs associated with AIDS, Alzheimer’s disease, or cardiovascular disease (Leigh et al., 1997). Within a business, the effects of sub-optimal integration of social and technical systems extend far beyond health and safety to affect output volume, lead time, production flexibility, quality levels, and operating costs. Joint optimization is essential for businesses to execute their strategies and remain competitive (Dul & Neumann, 2009).

1.2 The design of work systems

According to socio-technical design theory (see section 2.6), the organizations within which people work consist of social and technical sub-systems which interact to form the work system. In order for work systems to be optimally designed, social and technical sub-systems must be created to work together and the relationship between them should be optimized. Unfortunately, joint optimization of social and technical sub-systems is not often realized in work system design.

Researchers frequently explain this disconnect in the design of social and technical systems as a product of the organization of the work system design process, in particular the way feedback on system outcomes reaches the designers (Broberg, 2007; Dul & Neumann, 2009; Neumann et al., 2002; Perrow, 1983). Perrow (1983) argued that design engineers and management were isolated from the effects of their design, which were predominantly experienced by system users. Neumann et al. (2002) take this concept further, specifying that while system designers such as engineers, receive feedback on their work, it is technical in nature. Human effects were diverted to an organizationally isolated health and safety department (Helander, 1999; Jensen, 2002; Neumann et al., 2002). As a result, ergonomists tend only to be made aware of social issues within the work system and engineers tend only to be informed of technical issues within the work system. Therefore, it is not surprising they often work in separate domains.

While some researchers have described the design process in linear, rational terms (Hammond et al., 2001), the design of production systems has been observed to be a complex social process that at times appears irrational or non-linear (Engström et al., 1998) and includes micro-political dynamics (Broberg & Hermund, 2004). Even in technical fields such as engineering, design is frequently described as a social, negotiated process between individuals who interpret the world through vastly differing mental models, philosophies and values (Bucciarelli, 1988; Garrety & Badham, 1999; Kilker, 1999; Piegorsch et al., 2006). In addition, the influence of culture, from both within and outside the organization, is widely acknowledged to influence design decisions. Working against the existing culture to achieve different design results is difficult and often unsuccessful, requiring a different skill set than other core work system design tasks (Broberg & Hermund, 2004; Perrow, 1983). Due to the social nature of the design process, collaboration between professional groups is essential to the success of a project (Bucciarelli, 1988; Kilker, 1999).

The project 'Work System Design: A Study of Professional Practices among Ergonomists and Engineers' studies the roles and practices of engineers and ergonomics specialists in the design of safer, more productive workplaces. Engineers and ergonomists were chosen for the study because they were viewed as clear representatives of technical and social work system designers respectively.

1.2.1 Ergonomists

According to the International Association of Ergonomics (2000):

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

Ergonomics specialists apply their knowledge of how humans interact with technology in order to optimize the performance of new and existing systems (International Association of Ergonomists, 2000). Research has shown ergonomists frequently work to address specific work system concerns, have a short-term dialogue with the users of their system, and focus on short-term evaluation of system outcomes. In addition, recommendations tend to be developed in isolation from the attitudes and beliefs that managers and system users have about ergonomics (Whysall et al., 2004).

In reaction to the systems perspective of design, it has been suggested that ergonomics specialists must embrace a new role to improve their effectiveness at eliciting change within organizations: the role of the 'change agent' - focusing on preparing for and facilitating change within organizations (Badham & Ehn, 2000; Broberg & Hermund, 2004; Hasle & Jensen, 2006; Jensen, 2002; Launis et al., 1996; Wulff et al., 1999a). This idea is supported by the observation that ergonomists working in the ‘change agent’ role can support application and improve adoption of ergonomics related regulations by design engineers (Jensen, 2001; Wulff et al., 1999a) as well as the failure of regulations alone to sufficiently improve health and safety (Jensen, 2001; Rasmussen, 1997; Wulff et al., 1999a). In order to improve their effectiveness in this role, human factors specialists must learn to navigate organizations and appeal to the priorities of designers of all disciplines and levels of seniority, including industrial engineers (Badham & Ehn, 2000; Broberg & Hermund, 2004; Bucciarelli, 1988; Burns & Vicente, 2000; Hasle & Jensen, 2006). Therefore, the results of this study may provide information that will help ergonomists be more effective negotiating the design process within their organizations.

1.2.2 Engineers

This research is approached from the viewpoint that engineers have a significant role to play in the integration of ergonomics to workplace design and are key stakeholders in the ergonomic change process. Accurate, unbiased discussion of the methods and practices used by engineers is underrepresented in academic literature to date (Trevelyan & Tilli, 2007). In addition, despite the noted influence of culture on the way engineering is practiced (Adams, 2007; Lynn, 2002), none of the studies reviewed were done in Canada. Therefore, it is difficult to judge the relevance of the systems perspective of design presented on the work of Ontario’s industrial engineers. This study aims to provide insight on the day-to-day work of engineers, as well as the unique constraints and demands placed upon them when working on work system design related projects.

Engineers are a widely varied professional group, both within and between disciplines, differing by level of experience, role in the organization (Darr, 2000), and the surrounding culture (Adams, 2007; Lynn, 2002). The attitudes and working styles of engineers in different contexts may be very different. Thus it was essential to narrow the scope for feasibility and coherence in the sample group. Industrial engineers were chosen for this study as, like ergonomists, they are interested in the efficiency, effectiveness, sustainability, and safety of the work systems they design and improve. In addition, all industrial engineers receive some training in human factors and thus are well positioned to provide information on the topic of interest (Turner et al., 1978).

1.3 Objectives

The objective of this thesis is to illuminate the ‘gap’ in the design of social and technical systems from the perspective of a particular design stakeholder – the industrial engineer. This has been approached through the creation of a baseline data description of how industrial engineers approach work system design; in particular, the methodologies and organizational conditions they find most effective in applying ergonomics and ensuring the integration between social and technical systems in design. Though much data exists on the relationships between humans and technology, there is little standardized advice for how to apply this knowledge effectively and preventatively in an organizational context. This research will contribute to the field of industrial engineering by providing a description of how ergonomics knowledge is typically applied within organizations and how this application, and subsequently work system outcomes, can be improved.

A qualitative approach was considered most beneficial due to the lack of existing data on the specific work practices of industrial engineers (Trevelyan & Tilli, 2007). Qualitative methods are useful to explore new areas of study, address the question of “why” events occur, or describe social phenomena – such as the behaviour of a professional group (Hancock, 1998). Inductive methods found in qualitative research serve the aims of this thesis by providing the clearest description possible of how design occurs in practice, while minimizing the influence of researcher preconceptions. In addition, flexible and exploratory methods allow identification of relevant issues for future investigation through hypothesis testing.

The aims of this thesis are to:

1. Understand how industrial engineers work in an organizational context.
2. Identify the ecological factors which impact industrial engineering practice, particularly in regard to ergonomics.
3. Identify immediate and long-term suggestions for improving the application of ergonomics in the work system design process.

Theoretical background relevant to interpreting the results is provided as well as a complete description of study methodology. Results are presented in reference to the researcher’s framework for analysis, presented in section 2.7. Finally, key results, practical implications, and recommendations for future work are discussed.

Chapter 2
Theoretical background

Theory was applied to explain and interpret study results. Relevant models were selected based on the researcher’s background knowledge and investigation into the literature surrounding key themes in the interviews. The social ecological model, the systems model for work system design, organizational structure, participatory ergonomics, role ambiguity, and socio-technical design theory are described. Finally, a composite model is proposed to structure the description of study results.

2.1 Social ecological model

No design decisions are made in isolation. Designers are influenced by all aspects of their surroundings. Fellow designers, organizational constructs, and cultural and societal elements interact with the designer and each other to form a complex ecology which affects the final artifact produced. The social ecological model was created by Urie Bronfenbrenner (1979) to describe the way environmental factors influence human development. Bronfenbrenner conceived the ecological environment “topologically as a nested arrangement of concentric structures, each contained within the next” (1979, p. 22). Bronfenbrenner describes three of these internal structures as follows (Figure 2.1):

- **Microsystem**: the microsystem primarily describes roles and interpersonal relationships within a given setting.
- **Mesosystem**: the mesosystem is the organizational or institutional context surrounding the individual.
- **Macrosystem**: the macrosystem essentially refers to the surrounding culture or society.

Bronfenbrenner's work focused on childhood development, but his model applies to a broad range of topics, including work system design. Moray adapted the concept to describe the setting of ergonomics design using nested structures similar to those in the social ecological model (Moray, 2000). As well, Broberg (2007) used a framework reflecting the social ecological model to describe the factors influencing the integration of human factors into engineering work.

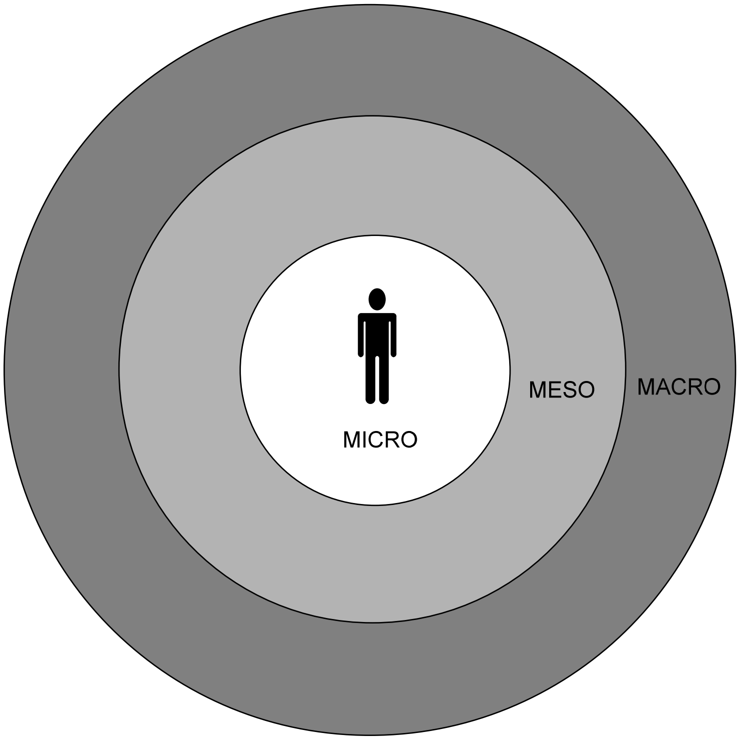


Figure 2.1: Social ecological model - The behaviour of an individual (at centre) is influenced by macro-, meso-, and micro structures.

Klein et al. (1999) explain the usefulness of multilevel theories, such as the social ecological model, in the investigation of a number of contexts. The benefits of this type of model are described as providing: “a deeper, richer portrait of organizational life – one that acknowledges the influence of the organizational context on individuals’ actions and perceptions *and* the influence of individuals’ actions and perceptions on the organizational context.” (p.1) In addition: “multilevel theories may illuminate the steps organizational actors may take, individually and collectively, to yield organizational benefits.” (p. 1). These attributes make multilevel theories such as the social ecological model well-suited to understand and interpret the organizational factors influencing the work practice of industrial engineers.

2.2 Systems model of work systems design

The systems model describes work system design at the mesosystem level. The use of a systems model in work system design has evolved over time (Neumann et al., 2002; Winkel & Westgaard, 1996), however, as a framework for this study, the following version of the systems model has been adopted (Neumann et al., 2009).

This model, shown in Figure 2.2, considers a number of design stages, or aspects, including 1) organizational strategy, 2) production strategy, 3) system design, and 4) the production system which users interact with (Neumann et al., 2002). These stages are related in an effort to describe how risk factors and eventual disorders emerge as outputs, along with productivity and quality levels (Neumann et al., 2002).

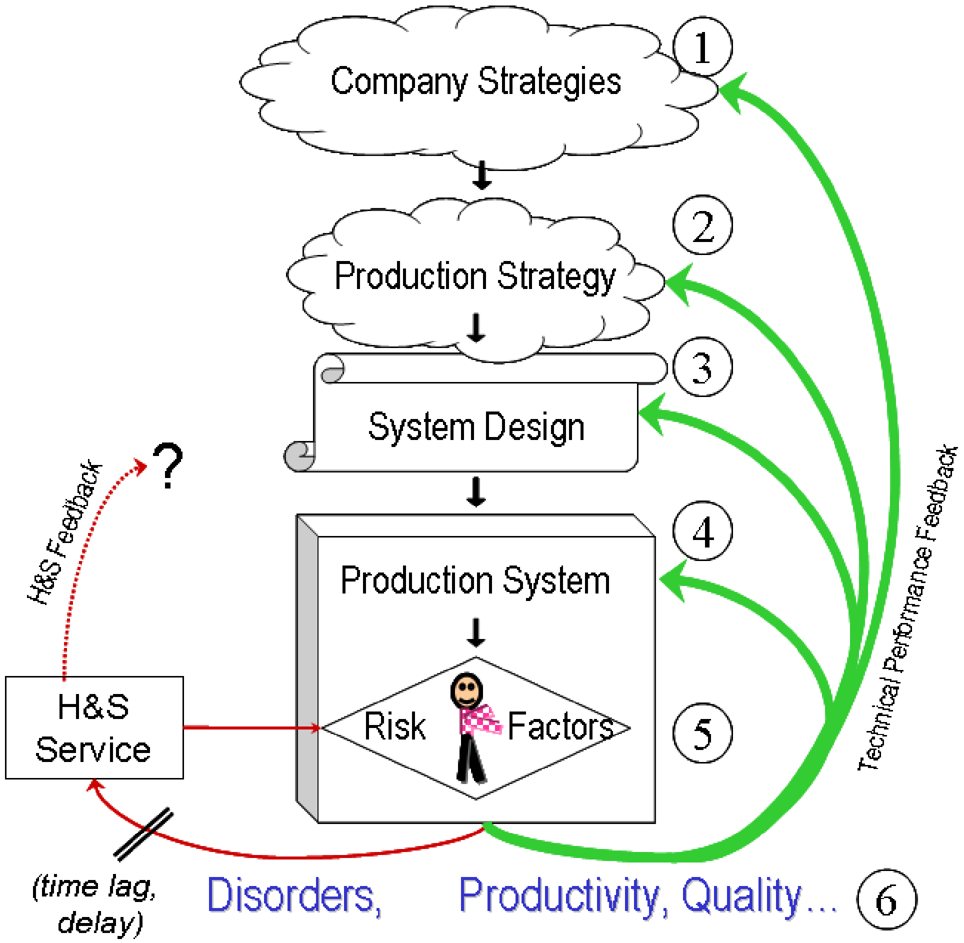


Figure 2.2: Systems model (Neumann et al., 2009) **-** Strategic direction (levels 1 and 2) for the design of work systems (level 3) which are implemented in the production system (level 4), can lead to risk for system users (level 5) and subsequently to adverse human effects as an unintentional system output along with the intended system outputs, including efficiency and quality (level 6).

The model presents the consequences of a series of decisions, beginning with strategic direction (levels 1 and 2) for the design of the system (level 3) that, once operational in the production system (level 4), can lead to risk for system users (level 5) and subsequently to adverse human effects (level 6) as an unintentional system output along with the intended system outputs, such as efficiency and quality. According to this model, groups of designers at each system level influence human factors directly through their design decisions, and indirectly through the interaction of their respective contributions from which human factors problems can emerge

(Neumann et al., 2009). These emergent system properties can be difficult to manage in design as influence is dispersed amongst design groups - no one person is in control of human factors (Launis et al., 1996).

‘Systems’ theorists are well aware of how communication barriers between groups can lead to dysfunctional effects and sub-optimal performance of the system as a whole (Skyttner, 2001). This is reflected in the limited feedback on human factors available to designers and strategic decision makers who, at higher levels of the design process, are increasingly isolated from their system’s effects. Exacerbating the problem, decisions made at higher organizational levels tend to be central to the system design, and thus tend to be heavily entrenched in early design work, making change more difficult and expensive as the production system nears completion (Miles & Swift, 1998). When health and safety problems do emerge from the interaction of different design aspects, they are usually delegated to the health and safety service who are generally trained to focus on the risk factor level (level 1). This isolating organizational structure has been described as the “side-car” approach to health and safety and is criticized as being ‘too little too late’ (Helander, 1999; Jensen, 2002). There appears, therefore, to be an organizational gap between work system designers’ influence on, and the ergonomists’ accountability for, human factors in design and operation of work systems (Neumann et al., 2002).

2.3 Informal and formal organization structure

An organization can be defined as “an administrative and functional structure” (Merriam-Webster, 2009). Research on organizations often characterizes this structure as consisting of ‘formal’ and ‘informal’ relationships (Blau & Scott, 2003; Johnson et al., 1994). Due to the complexity of organizations, informal and formal structures can exist concurrently.

Johnson et al. (1994) describe formal structures as “the configurations resulting from formal authority relationships represented in the organizational hierarchy, from differentiation of labor into specialized tasks, and from formal mechanisms for coordination of work” (p. 112). They go on to describe informal structures as those that are “not solely based on the positions individuals occupy within formal organizations” (p. 112) and which “function to facilitate communication, maintain cohesiveness in the organization as a whole, and maintain a sense of personal integrity or autonomy” (p.112). Individuals within the organization utilize these structures to navigate through the organization and gather resources to achieve their goals and objectives.

2.4 Participatory ergonomics

Participatory ergonomics (PE) is defined as “the involvement of people in planning and controlling a significant amount of their own work activities, with sufficient knowledge and power to influence both processes and outcomes in order to achieve desirable goals” (Wilson & Haines, 1997 p. 492). It is considered an ‘umbrella term’ and can refer to a strategy or approach, a method, a specific program, or a set of tools and techniques (Haines et al., 2002; Vink et al., 2008; Wilson & Haines, 1997). Key characteristics of a participatory ergonomic project include:

- *Involvement*: Whenever possible, employees from all areas of the organization should have equal opportunity to participate in the PE process and equal representation on redesign teams (Clement & Van den Besselaar, 1993; Institute for Work and Health Knowledge Transfer & Exchange Staff, 2008; Nagamachi, 1995).

- *Knowledge:* participants should receive training on ergonomics and have access to experts when required (Institute for Work and Health Knowledge Transfer & Exchange Staff, 2008; Nagamachi, 1995; Wilson & Haines, 1997).
- *Power:* Workplace change should be democratic. Participants must have real influence on decisions (Institute for Work and Health Knowledge Transfer & Exchange Staff, 2008; Wilson & Haines, 1997).

Each of these characteristics should be incorporated in order for a project to be considered truly participatory.

There are several frequently cited benefits of a well-executed PE program. Participation allows an organization to maximize the use of employees' implicit knowledge in order to improve operations. This applies not only to ergonomic issues, but often evolves to address all areas of the work system (quality, productivity, etc.) (Lanoie & Tavenas, 1996; Theberge et al., 2006; Wilson & Haines, 1997). In addition, by involving users in the development of new designs, a sense of ownership is established and resistance to change is reduced. User familiarity with the system may also decrease the amount of training necessary, further easing implementation (Haines et al., 2002; Nagamachi, 1995; Wilson & Haines, 1997). Finally, PE can help to ensure user input is continuously incorporated into redesign efforts (Vink et al., 2008), allowing for all the gains associated with early application of human factors. Review papers report PE has potential to reduce ergonomic risk factors in the workplace (Cole et al., 2005; Rivilis et al., 2008) while remaining cost-effective in the long term (Lanoie & Tavenas, 1996). These benefits of PE, such as operational improvements, ease of implementation, reduced training, and improved integration of social and technical systems, could all contribute to the effectiveness of industrial engineering practice.

Unfortunately, research has not established firm conclusions about the effectiveness of PE, and while there is a consensus about the benefits that may be drawn from PE, there are no guaranteed methods to obtain them. Reporting on PE projects is inconsistent and often does not include the detail necessary to systematically evaluate the technique (Cole et al., 2005; Haines et al., 2002; Hignett, Wilson, & Morris, 2005; Rivilis et al., 2008). Hignett et al. (2005) report a lack of quality evaluation and a potential publication bias against reporting negative findings on PE. They hypothesize that practitioners of PE may be reluctant to publish unsuccessful attempts at PE and that companies neglect to attempt any kind of evaluation for PE projects that are clear successes or failures. Haines et al. (2002) note that the successful examples of PE published often lack key information about the methods used or fail to provide convincing insight on why their particular methods lead to success. As a result, it is difficult to place results in context and to form overall impressions of PE practices (Haines et al., 2002; Wilson & Haines, 1997).

In order to help guide further research into PE while clarifying and organizing the information on current approaches, Haines et al (2002) developed the Participatory Ergonomics Framework (PEF) to describe and classify PE projects more consistently while capturing the diversity of the field. This framework has been adopted in subsequent studies of PE (Hignett et al., 2005; Rivilis et al., 2008; Vink et al., 2008). The PEF includes a dimension describing the degree of involvement of ergonomics specialists in change efforts. This dimension has been adapted to the context of industrial engineering to describe and discuss the interaction and collaboration of industrial engineers with system users and system designers, as detailed Table 2.1. Considering how industrial engineering work fits this dimension may help capture elements of participation in existing work system design processes, and indicate whether participatory techniques would be useful or feasible in work system design overall – not just in ergonomics.

Table 2.1: How industrial engineers may view the role of system users and its effect on work system design practice

Role of System User	Description
Consultant	System users are consulted by industrial engineers only occasionally, primarily to ensure they will not resist proposed changes to the work system. In comparison to the PEF, the system user is ‘available for consultation.’
Expert	System users are considered domain experts and are sought after by industrial engineers for information about the work system. In comparison to the PEF, the system user ‘trains participants’ (industrial engineers).
Team Member	Industrial engineers collaborate with system users frequently throughout the project for information, suggestions and feedback. In comparison to the PEF, the system user ‘acts as a team member.’
Client	System users are considered to be the central members of the ‘design team.’ The industrial engineer will often let them guide the change process and act as a coordinator or consultant. In comparison to the PEF, the system user ‘initiates and guides process.’

2.5 Role ambiguity

As described by Rizzo et al. (1970) “Role theory states that, when the behaviors expected of an individual are inconsistent - one kind of role conflict - he will experience stress, become dissatisfied, and perform less effectively than if the expectations imposed on him did not conflict” (p. 151). This has been shown in many domains, including professional organizations, hospitals (Rizzo et al., 1970), manufacturing environments (Ivancevich & Donnelly Jr., 1974) and the military (Bliese & Castro, 2000). Thus, comments by participants indicating role ambiguity were noted as potentially detrimental to the effectiveness of industrial engineering practice and to the well-being of industrial engineers.

2.6 Socio-technical design theory

The term socio-technical system was formulated by Trist & Badham in 1951 (Pasmore et al., 1982) to describe the organizations in which we work. It is stated that, “The concept of the socio-technical system was established to stress the reciprocal interrelationship between humans and machines and to foster the program of shaping both the technical and the social conditions of work, in such a way that efficiency and humanity would not contradict each other any longer” (Ropohl, 1999 p. 59). In essence, the organizations in which people work are made up of people who produce some product or service using technology, and both these people and technologies affect the effectiveness and suitability of the other (Pasmore et al., 1982).

A key principle of socio-technical systems theory is that the social and technical systems comprising an organization must be jointly optimized in order to be effective (Cherns, 1987; Pasmore et al., 1982; Trist, 1981). Pasmore et al. (1987) describe joint optimization saying: “an organization will function optimally only if the social and technological systems of the organization are designed to fit the demands of each other and the environment” (p. 1182). Cherns (1987) specifies further, noting joint optimization does not mean simply the alteration of technical systems for social reasons. In order to achieve desired system outcomes, all design decisions must be made with both technical and social objectives in mind.

Socio-technical design theory has been re-interpreted and applied in numerous ways (Pasmore et al., 1982; Trist, 1981), however, it is comprised of several agreed upon principles (Cherns, 1987; Pasmore et al., 1982). Cherns (1987) defines ten principles of socio-technical design. These principles are described as follows (Principles nine and ten have been omitted as they primarily apply to creation of socio-technical systems, rather than describing characteristics of a functioning socio-technical system.):

1. Compatibility: In order to be effective, the joint optimization of social and technical systems is necessary. Designers have conflicting goals and objectives and must learn to work together and reach decisions by consensus.

2. Minimal Critical Specification: No more should be specified about the work of system users than is absolutely necessary. For example, it is often important to precisely define what has to be accomplished, but not necessarily how the work should be done.

3. Variance Control: Variances are deviations from a goal or objective, in any aspect of an organization's activities or processes. Variances should be controlled as close to their source as possible and not exported across organizational boundaries.

4. Boundary Location: Cherns (1987) states: "Organizational boundaries should *not* be drawn so as to impede the sharing of information, knowledge and learning" (p. 156). Poor boundary location can cause role ambiguity and confusion of ownership in the system.

5. Information Flow: Information should be available to those who need it, across organizational boundaries. Information systems should be compatible with the needs of those who access information and those who must provide it.

6. Power and Authority: System users should have the power and authority to command the equipment, materials, and other resources required to do their work. As a counterpart, they should assume responsibility for using these resources efficiently and effectively.

7. Multifunctional Principle: Organizations can adapt to their environments either by adding new roles or modifying existing roles to be more multifunctional. If new expertise is required, expanding the range of responsibility for existing roles is preferred. Adding expert roles to the system can result in role ambiguity and confuse chains of command.

8. Support Congruence: Incentives and rewards must support the behaviour desired from the system. Support services, such as financial planning, purchasing, and planning, should be congruent with the other principles of socio-technical design, such as boundary location (4) and minimal critical specification (2).

Many results observed can be linked to the value of these principles for achieving effective work system design processes and are reflected on in the discussion section.

2.7 Integrated model for the social ecology of industrial engineers

Interview data was compared and contrasted to theory by the author in an attempt to develop a customized framework to describe the researcher's interpretation of the ecology surrounding industrial engineering practice. Combining the relevant characteristics of the social ecological model and systems model as identified above, a new framework for describing the social ecology of industrial engineers emerged. The relationships between industrial engineers and other system designers, including ergonomists, have not been included in the framework as the interviews provided less detail about these interactions.

Shown in Figure 2.3, this framework is comprised of four parts:

1. The Macrosystem: This portion of the model describes societal and cultural influences outside of the industrial engineer’s organization.
2. The Mesosystem: This portion of the model describes organizational factors impacting industrial engineers.
3. Industrial Engineer – Management interface: This portion of the model describes where industrial engineers are placed in the organization relative to higher-level decision makers; and characteristics of the relationship between management and industrial engineers which impact the ability of industrial engineers to achieve their objectives.
4. Industrial Engineer – System User interface: This portion of the model describes the system users’ place in the organization, including the relationship of system users with industrial engineers and other stakeholders.

While management and system users are part of the organizational factors influencing industrial engineers, participants had personal working relationships with these stakeholders. Therefore, factors affecting the individual working relationships of industrial engineers with these groups are described separately from the mesosystem portion of the model.

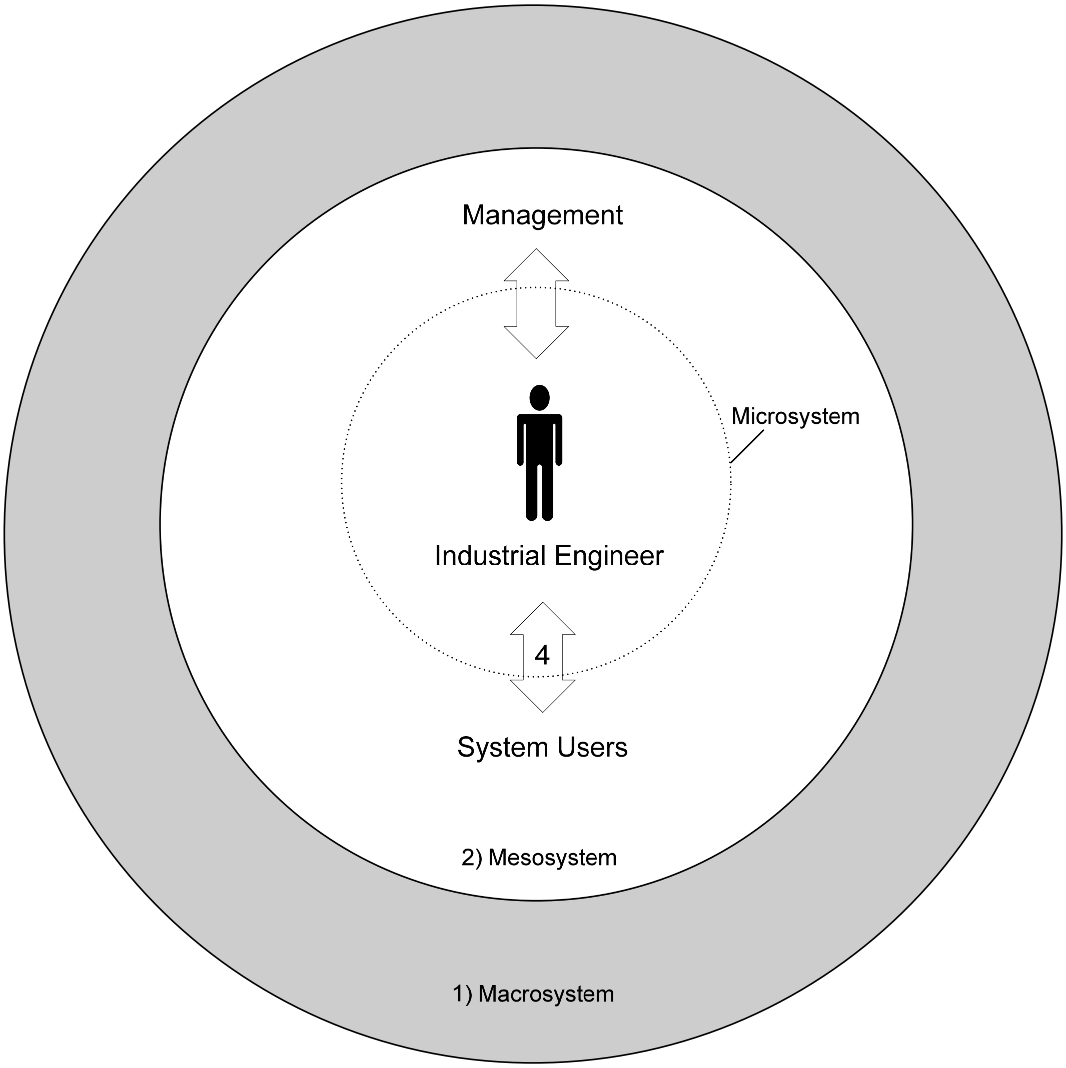


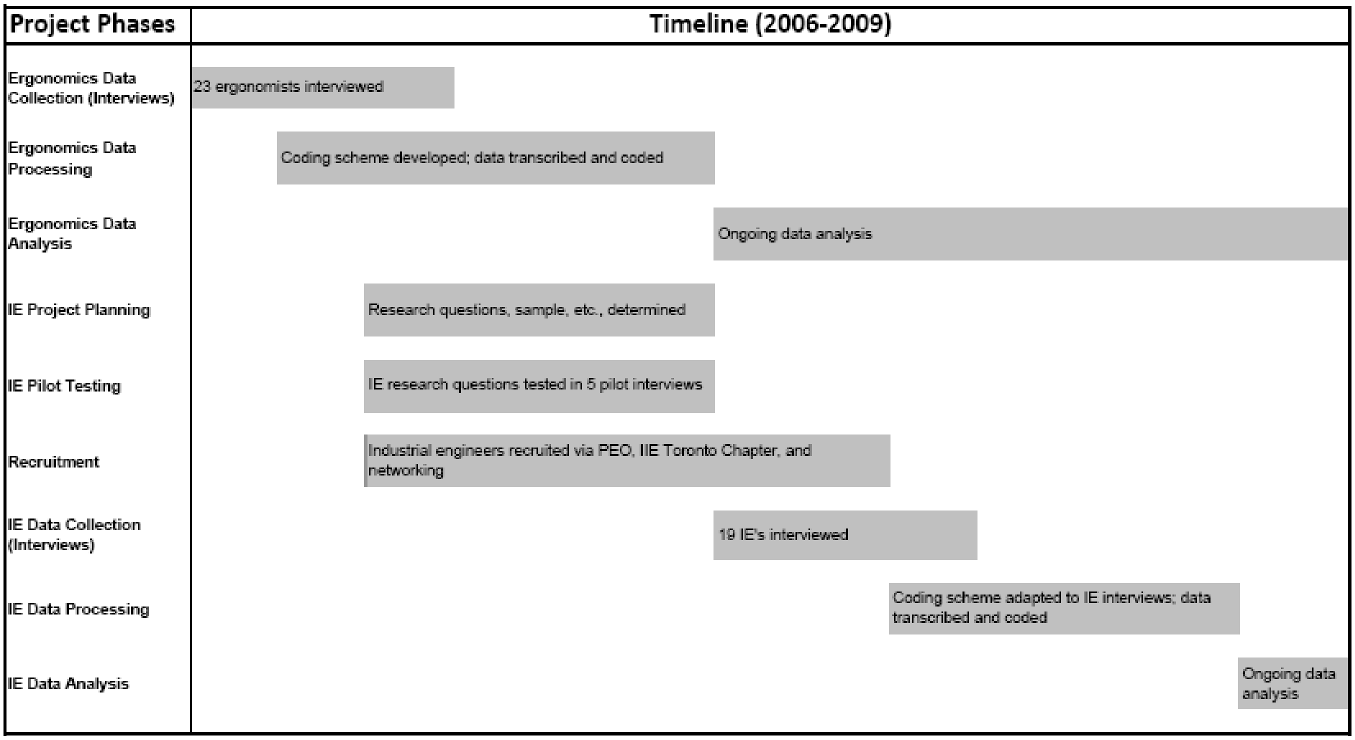
Figure 2.3: Integrated model of the social ecology of industrial engineers – the work practice of an individual (at centre) is influenced by multiple factors in their surrounding environment, or ecology.

Chapter 3
Methods

3.1 Research context

The larger study which this research is a part of has been approached primarily through qualitative methods targeting professional ergonomists and engineers. The study of each professional group was approached as a separate sub-project. While each phase of the project was headed by a separate project lead, both were undertaken by a common, multi-disciplinary team of researchers. In addition, because the ergonomist interview phase of the project was completed first, methodological decisions for the engineering phase were informed by that experience. A timeline of the study is included in Table 3.1.

Table 3.1: Timeline for the 'Work Systems Design' project



Project Phases	Timeline (2006-2009)
Ergonomics Data Collection (Interviews)	23 ergonomists interviewed
Ergonomics Data Processing	Coding scheme developed; data transcribed and coded
Ergonomics Data Analysis	Ongoing data analysis
IE Project Planning	Research questions, sample, etc., determined
IE Pilot Testing	IE research questions tested in 5 pilot interviews
Recruitment	Industrial engineers recruited via PEO, IIE Toronto Chapter, and networking
IE Data Collection (Interviews)	19 IE's interviewed
IE Data Processing	Coding scheme adapted to IE interviews; data transcribed and coded
IE Data Analysis	Ongoing data analysis

While the engineering phase of the overall project has been framed as an industrial engineering/applied science problem, it has been informed by a multi-disciplinary approach. Researchers with backgrounds in sociology, kinesiology, ergonomics, cognitive and design sciences, and mechanical and industrial engineering have collaborated on all major research decisions. The team has served as an advising and steering committee through both the ergonomics and engineering phases of the overall project. The input of these individuals has helped to ensure internal consistency by the researchers performing day-to-day data collection and analysis tasks, while providing a check to ensure external validity with multiple theoretical views of the problem.

3.2 Participants

Study participants were identified with the assistance of the Professional Engineers of Ontario (PEO), the Toronto, Ontario chapter of the Institute of Industrial Engineers (IIE), and through networking by the research team. Recruitment of industrial engineers was based on participants' self-assessment of being involved in 'work system design,' as well as the interviewer's perception that they were working in the domain of interest. Work system design was defined for potential participants as including the process of creating, modifying or improving a system in a way that will affect the work of others (i.e. job description, work organization, work scheduling/pacing, work environment, workstation, and tools, etc.).

Participant selection was based on job description as the wide variety of job titles and job descriptions associated with the term 'industrial engineering' made further specification infeasible (Institute of Industrial Engineering, 2009a; Institute of Industrial Engineering, 2009b). A convenience sample (cf. Patton, 2002) was obtained; some consideration being made for variety in age groups, industry, level of work experience, and the position of the individual within the design process. No compensation was offered to participants. Data collection was approached with an approximate sample size in mind, based on the results of the ergonomics phase of the study (N=22); however, the final sample size was determined by the researcher's judgment of the progress of the interviews. The decision to conclude data collection was made as the data approached saturation; participants' responses became more consistent, common themes and patterns were recognizable in the data, and the researcher was confident they could provide relevant, useful insight into the research objectives (Sandelowski, 1995; Patton, 2002).

The sample included 19 industrial engineers (5 women and 14 men) with an average age of 36 years (standard deviation = 8.8, median = 36). All participants held degrees in industrial engineering and were currently working Canada (18 in Ontario, 1 in Alberta). They had an average of 10 years (standard deviation = 7.3, median = 10) of engineering work experience. The majority of participants were employed in the manufacturing sector (11), and the other participants worked in healthcare (2), retail (2), transportation and warehousing (2), information (1), and professional, scientific and technical service (1) sectors.

3.3 Data collection

Data was collected through a series of semi-structured interviews with the participating industrial engineers. Interviews were typically an hour in length and covered a range of topics related to the professional practice of industrial engineers, including their description of their roles as engineers, the types of projects they are engaged in, their relationships with stakeholders, challenges and opportunities they face in their work, and strategies they pursued to meet both opportunities and challenges.

Ethics approval was obtained from the Ryerson Research Ethics Board prior to commencement of the study and consent was given verbally at the beginning of each interview as shown in Appendix A. All information was stored on secure computer systems and names or identifying information was not stored directly with any audio or transcript files. Any excerpts from the interviews included in publications have been presented in a way that removes any potentially identifiable information.

Interview topics were informed by the goals of this thesis as well as the experience gained throughout data collection in the ergonomist interview phase of the project. The engineering interviews were designed to be compatible with the questions asked of ergonomists to allow future comparison of the data sets. The ergonomist interviews also provided guidance into which topics of conversation were most likely to provide insight into the research questions. Basic tenants of interview design were applied, such as interviewer neutrality, and open-ended, non-leading questions (Patton, 2002). The interview schedule was tested through five pilot interviews and refined to ensure questions followed a logical sequence, were clear, used the language and terminology of the participants, and covered all topics of interest. The final semi-structured interview schedule was treated as a guide and topics of interest were pursued at the interviewer's discretion (see

Table 3.2 for a list of interview questions and Appendix B for the full interview guide).

Sixteen of nineteen interviews were conducted over the telephone and the remaining three done in person. Prior to their interview, participants were asked to fill out a short email questionnaire. This was designed to collect demographic data from the participants (age, gender, educational background, level of experience, etc.) as well as to help the interviewer prepare for the upcoming interview (tools used, number of engineers and ergonomists in their workplace, etc.). Except for the demographic data, all survey topics were discussed during the interview and are therefore not analyzed separately from the interview data. The full email questionnaire can be found in Appendix C and a summary table of survey results can be found in Appendix D.

Table 3.2: Interview questions for industrial engineers

Please describe your job.
Who do you usually work with?
Can you describe your company’s development process? Where you fit within it?
How would you describe your role in the organization?
How do your projects get initiated? How do you personally get involved in the project?
To what degree are you in control of your projects? Are you supervised?
How are projects prioritized?
What information do you collect at the beginning of a project? What is the source of this information?
What are the key constraints on your designs? How do you determine these?
What tools and methods do you use? In what circumstances do you use them? What are their advantages or disadvantages?
Generally, how are these tools selected? Is it just you or do any other stakeholders participate in the selection at all?

As you move through a project are there any standards you use to guide your design decisions? Are there indicators to assess the success of design concepts?

How do you know that your work on a project is done? What is your end point in the process?

Who signs off on new designs?

Once the project is complete what kinds of feedback do you receive? Do you follow up to see how your designs are working once they're implemented?

Is there a formal process for bringing health and safety into design at your company?

How does this play out in practice? How does it impact your work?

Beyond safety considerations, how are users considered during the design process?

What is your sense of the role of human factors specialists and the services they provide?

Have you ever been in a situation where you would've liked to work with a human factors specialist?

What is your opinion of the impact of ergonomics on performance?

Do you have any suggestions as to how ergonomics could be better addressed in design at your organization?

How could human factors better support your work? Is there a better way to present this information?

How could your job be improved? What aspects do you like/dislike the most?

Is there anything you'd like to add? Do you have any questions?

3.4 Data processing

All interviews were audio recorded and transcribed in their entirety by the interviewer. Transcriptions were then made available to participants to confirm their accuracy and to ensure the validity of the data collection process. Only minor modifications to the text were required, mainly due to transcription errors involving industry-specific terminology. Once the validity of these transcripts was confirmed by participants, they were then processed for ease of analysis.

In order to prepare the data for analysis, recurrent themes and topics of interest in the interviews were identified through review of the transcripts, consultation of the ergonomist interview results, and the original research questions. These themes were then organized into a coding scheme to be used to organize the interview data; each code representing a topic of interest for analysis. The creation of the coding scheme was done in reference to the codes used in the ergonomics phase of the project to ease comparison between the two data sets. This coding scheme was reviewed and revised in collaboration with the research team to verify that it accurately reflected the content of the interviews. Finally, the codes were tested on a subset of the interviews to ensure all topics of interest were captured. The full coding scheme is included in Appendix E.

Coding and sorting of the interview data was facilitated by use of NVIVO 7, a software package developed by QSR International. NVIVO 7 is a qualitative research analysis tool designed to aid researchers in managing large amounts of qualitative data. It allows the researcher to ‘sort’ passages of text into different codes for easier access to information during the analysis process. The coding process involved reading through each interview and identifying passages of interest which were then marked or ‘coded’ using NVIVO 7 so they could be easily identified and retrieved during analysis. Throughout the coding process the definitions of each code were refined and clarified and the coding scheme was updated to reflect this evolution.

3.5 Analysis

A general inductive process (Thomas, 2006) was used in analyzing the data. Essentially, the researcher reexamined certain codes identified during data processing to search for connections, patterns, and meaning in the data. Due to the scope of topics covered by the interviews, this analysis focused on a subset of codes which appeared to provide the most utility for the objectives of this thesis. After reviewing and comparing the content of all the codes, several were selected which formed a coherent description of the research issues. Seven codes formed the primary content under review; however additional codes were referenced throughout the process to provide further insight (see Table 3.3: Codes selected for analysis).

Table 3.3: Codes selected for analysis

PRIMARY ANALYSIS FOCUS	SUPPORTING CODES REFERENCED
Culture and Context Factors	Role of Industrial Engineer
Working relationships	Personal Perspectives on Ergonomics
Participation and Consultation	Feedback & Follow-up
Ergonomics Integration	Ergonomics Existing in Organization
Barriers & Assists	Future-oriented Discussions of Industrial Engineering
Managing Change	
Communication	

In order to interpret the data, the researcher performed several cycles of analysis. Each cycle began by examining the data and sketching a mental model of the information as the researcher interpreted it. This mental model was then checked against the data to assess how well it described the results. This re-examining of the data would start a subsequent cycle of analysis in which the mental model created would be updated and refined to reflect any new insights discovered. This practice could be described as moving iteratively between deductive (theory informs data collection) and inductive (data informs theory development) analysis styles (Orton, 1997) and is shown in Figure 3.1.

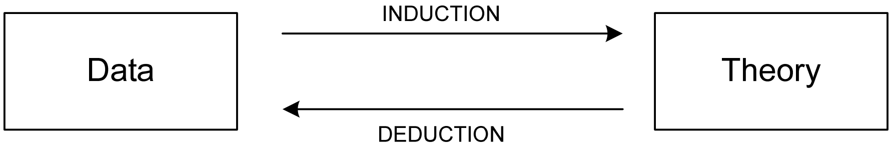


Figure 3.1: Induction and deduction

Eventually, a clear mental model of the results developed. The researcher then performed a literature search for existing theory that may help describe and structure the interpretations which had emerged, described in Figure 3.2. This process helped sharpen the definitions and language used in the description.

3.6 Reporting

Due to the iterative nature of the analysis process, it is difficult to separate the researcher's analysis of the data from the reporting of project results. Although the theory used to describe results continued to evolve throughout the analysis process, the most developed theoretical constructs have been used to structure the results of the study.

The results section of the report is organized by subheadings established during the data analysis process. The evidence collected to inspire the creation of each contributing element is then presented. The analysis structure is discussed in detail in the following discussion section.

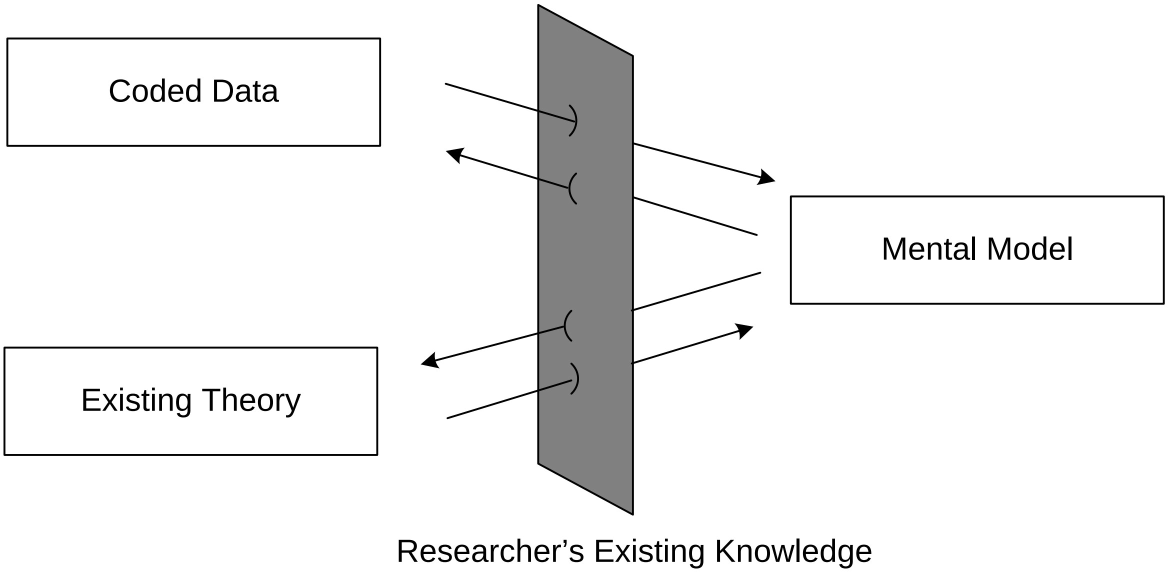


Figure 3.2: Overview of the analysis process: First, coded data was examined through the lens of the researcher's related experiences. As a mental model of the data developed, it was iteratively compared to the coded data until the researcher felt it was representative of the phenomena being studied. Once a descriptive framework had been developed, the researcher performed a literature search based on their prior knowledge of the domain.

Chapter 4
Results

Study results are presented in two sections: work strategies and working conditions. The working strategies of industrial engineers are described in terms of tool use, organizational navigation, and interaction with system users and other system designers. Working conditions of industrial engineers are described through the use of an ecological model of the factors which influence their work, as described in section 2.7.

4.1 The work strategies of industrial engineers

Descriptors of the working style of participants included the use of tools and methods, and their approaches to organizational work. Industrial engineers described a wide range of styles and methods for working towards their objectives within the work place. The strategies described are not discrete; some participants displayed a single, clear working style while others used a wide range of tactics depending on the context.

4.1.1 Tool use

Table 4.1 shows the most frequently reported tools as revealed by our pre-interview survey. Tools reported by less than 4 participants (20% of the sample) were not included in the results; however, the use of approximately thirty more distinct tools was recorded including technical standards and regulations, qualitative data gathering techniques, enterprise resource planning systems, and statistical analysis software tools (see Appendix F for a full list of responses).

Table 4.1: Tools reported in preliminary survey of industrial engineers

Tool	**# Participants who reported using the tool**
CAD tools (AutoCAD, Solidworks, etc.)	15 (79%)
Time Study (all methods)	15 (79%)
Equipment (tape measure, stop watch, camera, force gauge, etc.)	14 (74%)
Microsoft Office (Word, Excel, etc.)	12 (63%)
Ergonomics tool (checklist, list of standards, etc.)	9 (47%)
Process analysis (process charts, value-stream mapping, etc.)	9 (47%)
Lean tools and methods (reducing 7 wastes, 5s, etc.)	8 (42%)
Standard Time data (MOST, MTM, etc.)	8 (42%)
Simulation (Discrete event simulation, simulations with mockups)	8 (42%)
Six Sigma	5 (26%)
Standard operating procedures	4 (21%)
Failure Mode and Effect Analysis (FMEA)	4 (21%)

The majority of the tools reported were used in a general way, functioning more as theoretical guidelines rather than definitive tools. Tools such as Lean, Six Sigma, and process analysis are umbrella terms that include abstract concepts and many suggestions for methods of application. Industrial engineers apply these tools in diverse and flexible ways, often combining tools or creating new ones when necessary.

4.1.2 Organizational navigation

Participants used an array of strategies to achieve their objectives within the organization. These tactics were best defined by the organizational structures they utilized: formal or informal.

Formal

Several participants found the use of formal structures useful in meeting their goals and objectives. For example, one participant determined that formal structures were invaluable to securing the resources required for their work, explaining that to get the data required to do their work more quickly: *“you need to talk to somebody with authority and they have to enforce it.”*

In addition, others found that formal structures were practical during implementation to ensure their designs were executed the way they were intended. In order to control deviations from their design plan during implementation, one participant described using formal organizational structures, saying:

> “Once it becomes a document it becomes a bible that you can slap on the face and say 'hey, stop ordering other designs! This is our standard.' You are using your tools as an engineer to create something like a document to make it work.”

Finally, in the face of persistent resistance or hesitation, industrial engineers would use organizational power available to them to help achieve their objectives. As one participant expressed:

> “…of course also you use your authority, telling them that, 'Hey guys, I'm the industrial engineer so you have to listen. This is my proposal, let’s do it!' Because functionally, that's my role.”

While it was often noted that participants felt they did not have formal organizational support in their endeavors, utilizing the formalized advantages they did receive was a successful tactic in achieving certain organizational goals.

Informal

A majority of participants were equally, or perhaps more, comfortable navigating the informal structures of their organizations in order to achieve their objectives. Participants liked the option to pursue information or assistance from either system users or their fellow system designers without resorting to formal channels. One participant stated *“if I need help from someone they're always there, and I can bug them even if I have to so I can get the information that I want, the support that I want.”* When describing their work process, many participants had a great deal of freedom in their approaches. For example:

> “We go and talk straight to the operator, or the team leader, or whoever is required. So, it's not formal that I have to check with area leader whether I can go and talk to these guys or not, I just go and talk to those guys.”

Some industrial engineers were able to pursue their work independent of formal organizational structures. However, informal avenues were primarily pursued due to their practical value. In situations where formal requests may have been rejected, it was found to be more effective to argue their case using informal methods, as shown in the following passage:

> “…people are highly busy. They're swamped, they're exhausted, you've got to steal time through indirect action. indirect captures of time, either through cafeteria, or through an email, and so forth. You go about it in a very formal way, you'll get a very formal 'I'm busy, see me later.'”

Participants often relied on previously established relationships and goodwill in these situations to augment their official reasons for requiring assistance.

4.1.3 Stakeholder interaction

When describing their work, participants discussed their interactions with several stakeholder groups, including system users, management, and their more immediate colleagues. While interaction with management was primarily supervisory, work with system users and other system designers took the form of varying degrees of collaboration.

System Users

System users include any individuals within an organization who will work directly with the work system being designed by industrial engineers. For example, in a manufacturing context system users would include operators and other front line workers. Participants interacted with system users in a variety of ways, with working relationships ranging from minimal contact to collaborative. In order to describe these relationships a typology was created based on the Participatory Ergonomics Framework (PEF) (see Table 2.1, page 17). System users were viewed as consultants, experts, team members, and clients.

i. Consultant

At one end of the spectrum were system designers who had only a small amount of contact with system users. These participants primarily consulted users in order to gain buy-in to their design changes and ease implementation. For example:

> "You have an idea, you think it's going to improve something, then you need to make sure that the operators are going to buy-in to it first."

In this example, system users filled a ‘consultant’ role by providing their views on work system designs when requested.

ii. Expert

Many participants viewed system users as experts in their domain and an important source for design information. For example, it was stated that:

> “…in order for engineers to come up with the best solutions, we should have a very good understanding of the processes - very detailed understanding of processes - and no engineer, or no manager had that detailed information about the processes. The only choice we had was to work with those clerks to make them, or to ask them to explain what they do. Or at least let them, allow engineers to observe what they are doing.”

When system users filled an ‘expert’ role in work system design there tended to be more interaction between system users and system designers. System designers made a more concentrated effort to get feedback from system users at all stages of the design process.

iii. Team Member

Often participants sought to involve system users throughout the work system design process. When discussing the merits of engaging system users in design, it was stated:

> “I think feedback of looking yourself and actually asking the operator as well, is great. But I think asking the operator up front is even better, because you can involve them in your design. This way they feel more ownership and when they're actually working they feel like, 'you know what, I actually participated in this and this is what they're giving to me as a must and this is what you're supposed to follow.' So, they can embrace it more, and they will like it more.”

Industrial engineers viewed system users as ‘team members’ and collaborated with them throughout the design process. Information, suggestions, and feedback were continually gathered from system users and integrated into the work system design. Participants felt they were able to get a better sense of the jobs being performed within the work system and that they could improve their design outcomes.

iv. Client

A small number of participants sought to further increase the role of system users in work system design by giving them a leadership role in the design team. In this case the system users initiate and guide the design process, calling in industrial engineers when they require design expertise. For example:

> “What we're trying to do [… …] is get employees really involved in redesigning their own work, or re-balancing their own work. So, ideally, a group of people that do the same task over several shifts would get together and they would decide on how to improve a job, and then that would be the signal for us to go down and be part of the team to help make this improvement. So it's really a pull system, like where the floor asks us to help.”

In this scenario, the system user becomes the industrial engineers’ ‘client,’ and the industrial engineer takes the role of domain expert. One participant referred to his role as that of a *“coach,”* assisting or advising system users with design, but staying removed from the actual design team. In this case, participants had less contact with system users than when they were fellow ‘team members’ but felt it was appropriate because system users *“know more than anybody else.”*

System Designers

System designers are those individuals within the organization whose work will affect the jobs of others. Any designer contributing to the final work system design would be included in this category, such as other disciplines of engineers (mechanical, electrical, etc.), quality specialists, and logistics personnel. Interviews provided less detailed information on the interactions between industrial engineers and other system designers, as it was not prioritized as highly by the researcher; nevertheless, the data that was available indicated that collaboration between design colleagues follows a similar pattern to collaboration with system users. Participants perceived their fellow system designers in a range of ways, strongly influencing how industrial engineers proceed in their interactions with these colleagues. Evidence of participants viewing other system designers as consultants, experts, team members, and clients is briefly summarized.

i. Consultant

When colleagues are perceived as filling a ‘consulting’ role, industrial engineers appear to have a limited amount of contact with them. Participants consulted their colleagues on an occasional basis, primarily due to the logistics of working on a common system.

ii. Expert

Similarly to system users, design colleagues were often perceived as domain experts and a resource for information and advice. This tended to be a reciprocal relationship where colleagues shared information on a regular basis and most participants appreciated this opportunity. Conversely, participants recognized they were a “resource” for other functional groups within the organization, such as production, quality, and health and safety. In this situation industrial engineers benefited from easier access to information, as well as the opportunity to discuss their design concerns with other system designers.

iii. Team Member

Some participants reported working in design teams including stakeholders from many different functional groups. One participant described this saying:

> “We would form a team that represented a broad cross-section of functional areas at the firm. So, you would have somebody from materials, quality, production, engineering, and maintenance, for example. So you'd have a member from each of those departments.”

Fellow system designers were perceived as ‘team members’ who industrial engineers frequently expected to collaborate with. While this did not appear to be the most common way of organizing work system designers, participants felt it was effective. These teams allowed work system designers to ensure all design requirements were fulfilled by the design and that all subsystems were compatible.

iv. Client

In some situations participants assumed a more passive role in the design process. Industrial engineers acted as coordinators or consultants, but did not take a central role in making design decisions. In one organization, industrial engineers were *“…pretty much a resource for the production supervisor, and the plant manager, quality, and HS - Health and Safety.”* It was noted that the challenge of work system design is *“putting it together and getting people to buy* *into it, getting their support."* In some organizations *"that is the industrial engineering role: to coordinate the execution of the plan."* Participants appreciated the importance of coordination of design projects and appeared to have the skills and knowledge of the work system necessary to perform this function.

4.2 Ecological factors effecting industrial engineering work

Over the course of the interviews, a wide range of effects on industrial engineering practice due to contextual and environmental factors began to emerge. The participants themselves began to describe their own interpretations of external factors influencing their practice. These comments have been compared and contrasted with the integrated model for the social ecology of industrial engineering work, described in section 2.7. Each model element is broken down into the major topics discussed in the interviews.

4.2.1 Social ecological model

Several comments from participants suggested they viewed their work environment through a multilevel model similar to Bronfenbrenner's (1979) social ecological model. When discussing the factors influencing the design of work systems, they accounted for the range of factors that would influence the outcomes of this design, including societal and cultural factors, organizational factors, and their relationships with other stakeholders in the system.

Organizations were described as *"a very volatile, dicey place to be"* with *"mirco/macro-economics kind of overlaying the whole thing."* When discussing their strategy for analyzing a work system, one participant summarized their philosophy as follows:

> "A lot things work together, it's never just one... You kind of get a sense of things and ask enough questions to see if there's a pattern - and if enough people start clicking with symptoms of different parts of the problem, you start figuring out that – [… …] everything that happens is by design. Nothing's by accident. [… …] most often, people are just acting on the mixture of strategy, value... you know, all the things that affect, influence their behaviour and their actions.... Their behaviour's a by-product of all that."

All other participants also noted the influence of the environment in which their designs would be functioning. The author found that a three-level model of the ecological factors influencing work system design provided a good way of describing the concepts discussed. In the context of the social ecological model, the description of industrial engineers' direct interactions with system stakeholders could be considered a microsystem, intra-organizational influences a mesosystem, and extra-organizational influences as a macrosystem.

4.2.2 Where industrial engineers fit in the work system design process

Because industrial engineers could only describe the work design process from their own perspective, a less detailed version of the systems model of design (Neumann et al., 2009) was seen in the data.

Several participants referred to their organizational position as being *"…always stuck in the middle"* of management and system users. As one participant put it:

> “…you have two different people or two different groups of people that you work with. One is someone who's telling you what to do and what they need and then the other people that you have to get the information out of.”

In addition to management and system users, interactions with other system designers were also mentioned, however, perhaps due to the emphasis of the research questions, far less detail was provided on these interactions. Management, system users, and ergonomics specialists were the only specific stakeholder groups analyzed separately within the ‘working relationships’ code. System users were also described by an additional code, ‘Participation & Consultation,’ describing the way they were engaged in industrial engineering work. Additional discussion of working relationships was divided between a wide range of system stakeholders with minimal elaboration on the details of these interactions.

In the discussion of fellow work system designers, one characteristic of note was the emphasis of cross-functional interactions over the interaction with other industrial engineers. For example, *“The industrial engineering group... we don't pull ourselves together for a problem, we pull in -* [stakeholders from other functional groups]*.”* Industrial engineers tended to form teams by pulling in stakeholders horizontally across the organization to do their design work, while working vertically within the organization to ensure compatibility with the needs of the system. One participant stated:

> “We would form a team that represented a broad cross-section of functional areas at the firm. So, you would have somebody from materials, quality, production, engineering, and maintenance, for example. So you'd have a member from each of those departments.”

Essentially, rather than working as an ‘industrial engineering’ team, participants indicated they would assemble a team around each project consisting of stakeholders with the relevant abilities and responsibilities.

4.2.3 Describing ecological factors influencing industrial engineering work

Results were organized into four sections based on the integrated model of the social ecology of industrial engineers presented in the introduction. This model is divided into four elements:

1. Macrosystem
2. Mesosystem
3. Industrial Engineer – Management interface
4. Industrial Engineer – System User interface

The effects of each system element were considered from two points of view: impact on industrial engineering practice in general, and impact on the practice of ergonomics. Table 4.2 summarizes these results.

Table 4.2: Ecological factors influencing industrial engineering work

Model Component	**Definition**	**Major Factors Discussed**
Macrosystem (section 4.2.3.1, page 46)	Ecological factors influencing industrial engineering work at a societal or cultural level.	Economic conditions Labour market Regional norms Legislation
Mesosystem (section 4.2.3.2, page 50)	Organizational factors influencing work system design.	Design culture Organization size Organization structure Employee incentives and rewards
Industrial Engineer – Management Interface (section 4.2.3.3, page 57)	Characteristics of the interaction of industrial engineers and management that affect work system design practice.	Role ambiguity Power and authority Management support and understanding
Industrial Engineer – System User Interface (section 4.2.3.4, page 63)	Ecological factors related to the relationship between industrial engineers and system users which influence effectiveness of industrial engineers at work.	Job security of system users Trust Ergonomics awareness of system users

4.2.3.1 Macrosystem characteristics

In this model, the term ‘macrosystem’ refers to the culture surrounding the organizations in which industrial engineers work. The macrosystem factors influencing general industrial engineering practice and ergonomics practice are described as follows.

Macrosystem factors influencing the practice of industrial engineers included the economy and labour market, and regional norms and legislation.

The economy and labour market

Industrial engineers observed the impact of the economy and the labour market on both their duties and responsibilities and the willingness of companies to invest in industrial engineering efforts. The economic state of the industry they worked in, the availability and cost of hiring new system users, and the effects of outsourcing and globalization were all discussed.

One participant described how downsizing and cost-cutting within their organization has affected the variety and intensity of work by industrial engineers in their organization, saying:

> “Because, especially now with this situation in the market, you know, especially in auto-part manufacturing, they are trying to reduce their costs and reduce one person, or three, or four, it helps to have various skills. Unfortunately that's the way it is. And, it puts a lot of pressure on people.”

This appeared significant as the more work each individual is asked to take on, the less time they will have to the details of their designs and the follow-up work required to ensure that design elements are well integrated in the work system.

Economic factors also influence the overall investment in industrial engineering principles within a company. One participant noted that a colleague in China felt a lack of support for their work, saying *“…labour's so cheap, they couldn't even care less'.”* In this type of environment it is less likely there will be the organizational support and investment in the efficiency of the work system.

Similarly to the practice of industrial engineering, the practice of ergonomics within organizations was observed to be affected by economic factors. In situations of high unemployment, organizations may be able to get away with smaller investments in ergonomics. This point was illustrated by one participant, who stated:

> “I believe in human nature and international human rights, but I think businesses ... not businesses, but in some contexts it's not seen that way, it's seen as a function of supply-demand. Your rights are a function of your supply...and that's what I was trying to allude to with the labour market. So, if you know that there's a hundred people that would die to have your job, you're less inclined to complain about your wrist hurting when you do your job.”

In situations of economic uncertainty, system users may be less likely to raise concerns about health and safety and ergonomics. Furthermore, when employers perceive system users as easily replaced by new employees they may be less willing to investigate solutions for concerns that are brought to their attention.

Regional norms and legislation

Some participants observed that the region of the world they were working in may influence how they do their work. It was stated:

> “There's certainly outside factors and what's a preferable way of doing it. So something in North America that might be standard is not necessarily the way we'd go in Europe or Asia. So, you've got to look at local code, and what other people are saying. You might even look at the competition. How did they do things abroad? How do we compare to them?”

Regional considerations included differing standards, regulations and laws, as well as culture and attitudes about work. When reflecting on their international experiences, one participant stated:

> “The only thing they are thinking about in Canada is just working as little as possible and going for the weekend somewhere to have some beers. It’s not a German mentality. I'm not saying it is the right way of living, but what the company needs as a manager, as a leader is a guy who is putting something from himself. The way people are living here is good, I love it, but, it doesn't work actually. Rarely... what can I say... we need more than that to be better.”

If industrial engineers design with different regional norms in mind, their interpretation of an effective work system design may not match those of system users. These differences may also increase the complexity of collaboration with designers based in other facilities around the world.

The priority placed on ergonomics within an organization can be partially a function of regional attitudes about workplace health and safety. For example:

> “…in most cases in my experience in Canada, it’s always safety that prevails. Here. But in other countries, maybe its not. That's why I experience a little bit of that struggle. Because I realize that here in Canada the safety rules are always being interpreted very exaggeratedly.”

Regional values and attitudes toward work place health and safety and ergonomics may impact how standards are interpreted and how willing system designers are to strive for the realization of ergonomic principles.

Many participants felt that legislation around workplace health and safety did influence their organization’s investment in health and safety. As one participant put it:

> “Another way of getting in, I hate to say it, is legislative. We really need ... I mean the WSIB has done some good work, really more aggressive standards, you know. Really setting it up.”

In addition to provincial regulations, the affect of civil law was also felt. In one participant’s estimation, improving users’ working conditions was *“…not just their safety, its also avoiding lawsuits.”* It appears that at an organizational level, legislation can be an effective method of improving ergonomic conditions in work systems.

4.2.3.2 Mesosystem characteristics

The mesosystem refers to the surrounding organization or institution. The mesosystem factors influencing general industrial engineering practice and ergonomics practice are described as follows.

Four mesosystem factors influencing the practice of industrial engineering emerged from the data: design culture, organization size, organizational structure, and incentives and rewards.

Design culture within the organization

The prevailing organizational beliefs about the nature of design sometimes presented barriers to industrial engineering practice. Because industrial engineering interventions are often based on high-level views of the system in question, there can be resistance from stakeholders who do not share their vision. One participant described this issue in terms of training, stating:

> “... I mean it's very unproductive for the company in the short-term, but it's a long-term investment, and I would've changed the training for everyone in the company. Just to get them to become better collaborators. Just to teach holistic thinking skills. And a lot of times, that comes from the top because often the culture dictates just focusing on what's in front of you. Really getting the people energized and keeping the momentum is very hard.”

When higher-level, integrated perspectives on work system design were not appreciated or understood by their colleagues, participants were more likely to focus on short term solutions or improvements to a single work station when they may have preferred a more systemic approach. Thus design culture and the placement of organizational boundaries changed the way participants practiced work system design.

Management support of certain initiatives also relied on the company culture. It was observed that *“Old industries are still in the Taylor world where the worker can't be trusted”* and that *“…at the end of the day, nobody will trust that a group will make the right decision with nobody being a leader.”* In organizations operated from this perspective the possibilities for system redesign are constrained. In order to gain support, work system designs must fit within these surrounding organizational attitudes, adding further complexity to industrial engineering work.

Design culture also influenced the existence and the success of ergonomic interventions within organizations through the culture and awareness surrounding ergonomic issues in the workplace. It was noted that: *“progressive companies have figured out that employees have a long-term relationship with the company, so health and safety's important to them.”* This belief was demonstrated in policies such as *“tying financial performance with actual functioning of health and safety programs.”*

Of particular significance was the impact of organizational awareness of ergonomics on ability of industrial engineers to implement ergonomic projects. When describing the practice of ergonomics in their work, a participant stated:

> “See, the biggest challenge is... understanding the level of the team in general. And basically, going into the core of ergonomics improvements and everything you have to go in details, and you have to involve operators and everyone.”

Awareness of ergonomics by all parties in the organization significantly eased the execution of ergonomics projects.

Organization size

The size of the organization they worked in affected industrial engineers’ practice in two main ways. First, it affected the definition of their role. In smaller organizations or organizations with fewer industrial engineers, participants were required to become a *“jack-of-all-trades,”* and perform a wider variety of tasks. Secondly, the size of the organization also affected the way industrial engineers pursued their objectives. A participant working in a large, international organization stated:

> “I mean, the size is a huge factor. Just by example that we have so many managers who are off-site in different countries, right? So just simple logistics of coordinating meetings and waiting for people to get back to you. Because your whole team might not be in the Toronto general office, so I can't just walk five cubicles down and be like 'hey, so what do you think of this?' 'hey, so what do you think of that?'”

In large organizations it may be more difficult for industrial engineers to access the stakeholders in their design or obtain the necessary information to do their work.

Organization structure

Industrial engineers described their effectiveness as being influenced by their place in organizational structure. In particular, industrial engineers sought to be formally integrated into the central design process of their organization. One participant stated:

> “I think we would have been better if we were more embedded within the power structure, not outside of it. I was in an HR role. So, I was automatically seen as an outsider and the role would've been more effective if we were able to create a real incentive for every other department in the company to collaborate with us on these things.”

In general, participants desired “direct engagement with the production effort” and close contact with the systems they were working with. A stronger organizational position was necessary to work effectively.

Participants noted the need for a high degree of integration of ergonomics and industrial engineering principles into the work system design process for both technical and financial reasons. This was of particular importance when several design teams contributed to the final work system. One participant noted the effects of previous design decisions on their ability to create ergonomic work systems in their facility, saying:

> “You know a lot of it comes back to the part design, of the actual component these people are expected to handle. We have components in here and it's almost impossible to design a lift-hook for them. So, if the weight gets heavy enough we will design a lift-hook for them, but they've not really incorporated anything into the part to allow them.”

Because of the design of the part, incorporating measures to improve ergonomics, such as adding a lift-hook, was more difficult. Another example of lack of ergonomics consideration throughout the design process was related to packaging:

> “Sometimes the packaging becomes so complex that it's hard to get the part out of the packaging. Because they've got such tight criteria of what the packaging has to do to support the part that it's not easy for the operators.”

In this case, previously determined design criteria for packaging made the jobs of system users more difficult and later work system design more challenging.

In addition to the technical challenges resulting from poor integration, participants observed financial implications as well:

> “By the time it gets to us, if it's already designed and it's difficult to handle it becomes a lot more expensive. If you design the part correctly in the first place then you save a lot of money down the road. So, the design people themselves have to follow ergonomics guidelines, and sometimes they're not.”

Failure to consider ergonomics in early design decisions had far reaching effects, increasing the complexity and cost of applying ergonomics in later stages.

Integration of ergonomics in the design process had a notable effect on the practice of ergonomics by industrial engineers. The level of integration experienced by participants varied from virtually no ergonomics presence to full integration of ergonomics in the work system design process. When describing their organization’s approach to ergonomics, one participant stated:

> “At [Employer] we had simple instructions, but not comprehensive at all. One of the things I was working on actually was to improve that, but I didn't get the time unfortunately because I was too busy because of practical things on the floor.”

Still, most organizations did have some policies in place, creating the expectation of a certain degree of ergonomics in the work system. For example, mandating weight limits on parts delivered to the facility from employers or:

> “For example, most of our newer equipment, we would actually almost make it compulsory to have smaller stations to be height adjustable, so that an operator could adjust the height based on their needs.”

However, when describing the impact of organizational integration on ergonomics practice, it was frequently asserted that a more comprehensive approach would be preferred.

Depending on their placement within the organizational structure, industrial engineers had varying amounts of awareness of the impact of their design decisions. While many participants worked directly with system users, some were more isolated. For example, one participant described a past position saying:

> “So, the way it is with that job is you don't see it affecting people's work, because you're doing stuff really high-level, making decisions from a higher-level and its just system-based decisions.”

Close proximity to system users and the ability to view the effects of their design decisions first hand impacted how much participants felt accountable for ergonomics.

Employee incentives and rewards

Several participants related the rewards and incentives programs within their organizations to undesirable system outcomes. As one participant put it:

> “So this is another 'Chicken Soup for the Soul' type of statement: if you're incenting people on a particular behaviour, that is the behaviour you're going to get. Which goes back to the metrics. And people prioritize on what are they being incented.”

The following passage demonstrates the potential for highly inefficient behaviour as a result of a poorly conceived incentive program:

> “Or part of my incentive is, hey you know what, I do more than a hundred million dollars of sales. I might under cut my sister department just to out bid them, because I'm getting incented on revenue, but not results.”

Participants noted examples of this phenomenon at every organizational level, particularly among their peers and system users. In situations where incentives and rewards are incongruent with the desired work system outcomes, industrial engineers will have extreme difficulty improving effectiveness. Conversely, the outcomes of industrial engineering work can be expected to reflect organizational incentives and rewards, whether implicit or explicit.

A second model for employee incentives was to target the work system designers rather than work system users. For example:

> “It is one of the most important things in our company because our wages, our salary increases depend on it. There's actually a formula setup where HS and quality are actual factors on it. So if there's a recordable doubt here, that will affect our bonus for the next year.”

Similarly to the incentives and rewards for system users, incentives and rewards for system designers were observed to be ineffective when not based on indicators under their control.

Participants were aware of the importance of promotion and seniority to system users as well, and reflected this in their design decisions:

> “To give you an example, I call it the 'waiting for your turn in line', so let's say you're making a change and you're eliminating a whole level of management. So, let's say somebody had worked ten years, they've been waiting to be in that role for ten years and now you eliminate that. It's not fair to them. They were made, in a very undeclared way, they were made a promise. So, you've got to come up with all kinds of ways that you can keep people engaged because sometimes they actually have a fair point. Yes, change is great, but they lose. Some people actually lose. I mean that's the honest truth.”

Industrial engineers sought to preserve the expected career paths within their organizations to minimize the disruption of system users. Issues of seniority and promotion introduced another constraint into the work system design process, in addition to creating a source of resistance for system users and placing industrial engineers in the middle of management-system user relationship.

4.2.3.3 Industrial engineer – management interface

The industrial engineer-management interface describes the placement of industrial engineers in the organization relative to higher-level decision makers and the characteristics of the relationship.

Three characteristics related to the management of industrial engineers were influential to the effectiveness of their practice: role ambiguity, power and authority over the work system, and management support and understanding.

Lack of clear role definition

Participants consistently attributed a certain degree of role ambiguity as inherent to the domain of industrial engineering. For example, one participant describes the range of topics considered by industrial engineers, stating:

> “You get into really a lot of detail. It becomes a... there's a lot put on industrial engineering to really understand the process and understand all the parts. We need to know everything. Whereas control engineers need to know all about controls, and process engineers need to know about primarily automation, whereas industrial engineers need to know a little bit about everything.”

In addition to the array of content of industrial engineering work, it was commonly felt that there was a lack of clear definition of the industrial engineering role by superiors. One senior participant described this saying:

> “It’s not that they tell you what to do, but you have to think of what you have to do. That's the difference between an IE and a routine, other function. There are other jobs that are very routine, right? In the case of industrial engineers nobody will tell you what to do. You have to do it yourself.”

Many participants had a large degree of autonomy in their organizations and little direction. While some participants thought this was either a desirable feature of the job or a defining part of the industrial engineering role, others found it frustrating. An industrial engineer at the start of their career felt: *"A lot of things are up to my discretion. And I don't - this is part of the frustration - I feel like things are too loose for me."*

Role ambiguity on behalf of system stakeholders and the industrial engineers themselves created barriers to the consistent practice of ergonomics in work system design. When describing when they would call in an ergonomics specialist for a project, a participant said: *"The challenge with an industrial engineer is that we actually had training in this, like minimal training I would say, compared to a full ergonomist."* Industrial engineers felt they had some preparation to implement ergonomics in their designs; however, when they did have access to an ergonomist there was confusion about when they should contact an ergonomist and when they should address ergonomics issues themselves. Some even avoided engaging in ergonomics to prevent overstepping their role. One participant stated: *"I'm not involved in ergonomics that much. We have [health and safety] representatives, so I don't get myself involved."*

The confusion over the role of industrial engineers in ergonomics also extended to other stakeholders in organization. This is reflected in the following description of how ergonomics issues are addressed in the work system design process:

> "I think that [industrial engineers] could be more involved in that than they are right now. I think it's because they do take into consideration when they're designing, like operators and all that, but I think they should get more involved when the complaints come. [System users] should always come to us and make sure that we know, we can find a solution, and make sure that we can reduce or eliminate that problem. There aren't many right now, but kind of an informal way… I think we should have a procedure stating that when something like this occurs, this is what you're supposed to be doing, like a flow chart of what you're supposed to be doing."

It appears that despite the efforts of individual actors, the emergent nature of work systems creates confusion among stakeholders at all levels of the organization, causing inconsistent approaches to ergonomics practice.

Power and authority over the work system

Industrial engineers often faced obstacles at work due to their lack of control of the systems with which they worked. For example, when addressing work system concerns it was noted *"…my role is only recommendatory. If the people do not listen, I cannot implement because it's not like a direct engineering role."* While industrial engineers have the expertise to recommend design changes, they do not always have the power to execute them.

In some organizations, industrial engineering practice was complicated by the original system designer being in control of design changes. In this case, the industrial engineer must convince the original system designer that changes are necessary before they can proceed. One participant described their relationship with management, saying:

> "…[they are] the manager of [Organization Division], and [they are] like 'no, everything's totally fine.' Well, [they are] also... [They are] the one who has made it that way. Like this is [their] design."

Their organizational position made some industrial engineers reluctant to pressure those with control of the work system to make design changes due to the politics involved.

Lack of power over the work system remained a problem even when management approved the implementation of industrial engineering projects. The following passage describes the problems associated with lack of authority in the work system in which the participant’s work is being implemented:

> “We need supervisors, especially production supervisors and managers, who understand the industrial engineering role, and are willing to uphold the tools that we put in place for improvement. Because, typically, what happens in a company is that we are brought in to bring about those improvements, but we don't have control over the people and the processes to make sure that those improvements are actually being sustained.”

In order for work system design changes to have any long-term impact, those controlling the work systems must support and uphold the designs.

Management support and understanding

All participants stressed the importance of management support and understanding of industrial engineering practice. The relationship between industrial engineers and management was described as follows:

> “At the end of the day, the success of the industrial engineer… there are some limitations. Because, when you introduce something to higher management, they can argue. If they argue, you also need somebody at your back to argue for you. So it’s at another level. So, that's where the thing is. If the people at your back, meaning your boss, or whatever, is not strong enough also to face them, then of course you will suffer setbacks.”

Industrial engineers relied on their managers to support them in their interaction with both upper management and system users. This support was considered essential to achieving all goals and objectives within the organization. It was stated: *"unless you have a good management support, you can do nothing good."*

Even when they were backed by management, some industrial engineers felt discouraged by decision-makers' lack of knowledge about industrial engineering. This was a particular problem when attempting to establish an integrated approach to industrial engineering. For example, it was observed:

> "Well, I think the major barrier right now to the lean group is the lack of lean engagement due to management not knowing how to engage the lean group, and not knowing how to integrate the lean group into the production operations/the engineering operations."

Management's knowledge and understanding of industrial engineering principles influenced their ability to utilize industrial engineers effectively and their likelihood to support industrial engineers' initiatives.

Industrial engineers felt management support was essential to the number of ergonomics projects undertaken within the organization. One participant, who personally supported the application of ergonomics in work system design, recalled:

> "Because I was feeling [the initiative] was not good for health and safety of the employees, I was resisting against my employer, trying to convince them is not good for health and safety employees and it's better to change those initiatives. But at the end my employer had the choice whether he wanted to proceed or not."

Management often made the final decision on whether to go forward with an ergonomics project, as well as controlling the resources required for these projects. As one participant stated:

> “The engineer cannot do everything, no matter what their creativity or talent is, because he's not the guy, she's not the guy, who provides the budget for doing these kinds of things.”

Management was often noted to be reluctant to invest money in ergonomics projects, and therefore financial arguments were considered effective ways of gaining support. One participant described the impact of a motivated industrial engineer they had worked with as follows:

> “So he understood the ergonomics point of view, people's comfort, etc., etc., but also the economical return - essentially your return on investment. He was able to convince the management that this is what it will cost you if you don't care of it. So that company was very susceptible to changes and they had a whole team to do all of this work.”

When industrial engineers were able to successfully make an argument for ergonomics, they were occasionally able to significantly increase their organizations’ propensity for ergonomic changes in the future.

4.2.3.4 Industrial engineer – system user interface

The industrial engineer-system user interface describes the system users’ place in the organization, including the relationship of system users with industrial engineers and other stakeholders.

Two characteristics related to the relationship between industrial engineers and system users were influential to the effectiveness of their practice: job security/fear of reprimand and trust, and ergonomics awareness.

Job security and trust of system users

A significant factor in the ability for industrial engineers to do their work was the job security felt by system users. Fear of reprimand or being fired for doing a bad job led system users to resist involvement by industrial engineers. According to one participant:

> “You wouldn't believe how many good ideas that people can give. And, I guess they just need a chance, and they need someone to talk to them and make sure they're not scared of whatever they're going to say.”

The reluctance of system users to discuss their work with industrial engineers is resonated in the following passage:

> “I mean a lot people… people like employees in the middle and bottom are amazing. They'll actually do things with no reward. They're just afraid of the punishment that goes with it.”

Apathy, suspicion or resistance of system users created barriers for industrial engineering work, both in obtaining access to information and in the implementation of their designs.

The level of job security felt by system users greatly impacted their likelihood to report ergonomics problems, therefore affecting the ability of industrial engineers to address ergonomic issues. For example, it was noted:

> “If you're at a floor level, people won't say anything because they're scared of losing their job. It's very common, especially for a lot of immigrant workers, they're new to the country, don't speak English, this is their only primary source of income, they don't have a choice. They always will do the work without complaining. They'll work really hard, long hours and they'll take all the pain.”

When system users feared reprimand or job loss due to complaints about working conditions, system designers received far less feedback about the ergonomics of their work system design.

Many participants felt system users' trust was essential to their work practice. Trust-levels played out at several points in the design process. It was noted that: *"if [system users] don't trust you, they're not going to give you any information or any complaints."* This was considered a significant barrier to effectively focusing industrial engineering efforts within the work system.

Trust also impacted the degree of resistance industrial engineers experienced during implementation. Trust level was considered an important element in smooth implementation of work system designs. One participant reflected:

> "I think once you develop a reputation of really, exactly what I just said, trying to make it perfect as opposed to settling for something half-way, then when people see you coming along because of a problem they have they actually welcome that. Very often I hear things about resistance to lean and I have to say that in my experience if it's done the right way there is little resistance."

When industrial engineers were perceived to be dedicated to achieving positive results, system users were more open-minded to work system design changes.

The ability of system users to discuss ergonomic issues with industrial engineers was considered a major contributor to the effectiveness of ergonomic efforts. As one participant described:

> "Because, for the people on the floor, their health is the thing they need to make money. They are not sitting behind the desk, so their health is the first thing. So, they know very well if someone takes care of that part of the story, that's the guy who's trying to support you."

System users experience the most direct impact from work system design changes - their livelihood, health, and enjoyment of their job may all be affected. While this makes them particularly reliant on the effectiveness of work system designers, it also makes them an important partner in improving work system design.

In order to build a trusting relationship with system users, participants felt they had to overcome their association with management. As one participant noted:

> “we have to be very careful to not alienate the bottom because when we're coming in from that kind of a role, they're always going to think of us as being the 'voice of the top', so we have automatically establish that 'no, we're here to understand the problems of the bottom'.”

While working to achieve the mandate established by management, participants had to ensure that needs and objectives of system users’ were also preserved. If successful, a working relationship would be established where: *“It’s really a mutual relationship based on trust and a feeling that the [work system designer] is not the guy of management; he is our guy as well.”*

Ergonomics awareness of system users

Data suggests that awareness of ergonomics principles among system users can positively influence the practice of ergonomics by industrial engineers. One participant described ergonomics awareness throughout their organization:

> “Working with other people that I worked with, IT people or business people, marketing teams, or whoever that I worked with, they have no clue. They just see the comfort or no comfort, you get used to it. Unless it really starts hurting their back or something happens, then they would say something about it.”

Participants relied on feedback from system users to effectively identify the ergonomics concerns in the work system. One participant felt that providing system users with job specific information about ergonomics would make work system designers more thorough when addressing ergonomics concerns, stating:

> "I think awareness is very important. Operators need to be aware of... limits for example. So, if a company has guidelines the operators should know about those guidelines so that if there is any violation they can report to it. It's very hard for an industrial engineer, or anybody else, to actually be there at all times and measure every single thing, every weight, every height. So it's good that operators are aware."

This implies that ergonomics training should be directed to stakeholders in all areas of the work system. Some organizations did act on this idea. For example, an organizational stance on ergonomics training is described as follows:

> "There's certain groups that will be heavily trained in ergonomics, and then there are certain groups that will just have a touch on it, though. I think everybody - like even the union teaches ergonomics to the hourly people. So they get a taste of ergonomics and what their work ranges should be in, how much weight they should be lifting. So they've got an understanding of it at least. And then everybody else gets... all the salary people get some, and then the industrial engineers get a lot."

By increasing awareness of ergonomics throughout the organization, ergonomics concerns are more likely to be prioritized and addressed.

Fear, mistrust, and lack of awareness of ergonomics, often results in system users refusing to voice their ergonomics concerns. As one participant states:

> "So it's very, very common, especially in the lower workforce, or at the worker level, in factories or whatnot, it's very, very common. People just don't say anything."

As a result, management and industrial engineers are less aware of ergonomic conditions within the work system.

This can also have a considerable impact on the willingness of organizations to support ergonomics projects. The following passages describe the effects of system users' silence.

> "And I remember many times that I was going to do something but I was told, for example, don't do this because it costs a lot. Why? Because from labour side there was no pressure, there was no demand to make it better, and they were performing the way you are designing the process and operations without thinking how harmful it could be for their health, or not."

Industrial engineers had difficulty making a case for ergonomics changes in the absence of complaints from system users.

However, regardless of the countermeasures that may hypothetically be taken by management, the silence of system users appears to give organizations an excuse for ignoring ergonomics problems brought to their attention. As one participant stated, management *"…didn't care too much because there was no pressure from the other end."* When there were no complaints from system users, organizations were much more likely to ignore the effects of poor ergonomics.

4.3 Ergonomists and the social ecology of industrial engineers

The social ecological model of the system used to organize the results was based on the salience of each stakeholder relationship throughout the data set. Therefore, ergonomists were not included. However, a proportion of participants did describe interactions with ergonomists and their impact on the practice of ergonomics in their organizations. In these cases the model could potentially be expanded to include a fifth element, Industrial Engineer – Ergonomist interaction, Figure 4.1.

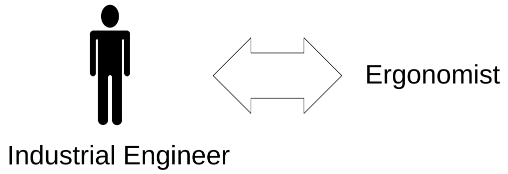


Figure 4.1: Industrial engineer - ergonomist interface

4.3.1 Frequency of industrial engineer – ergonomist interaction

The sample was broken down by the number of participants with access within their organizations to a specialist in either health and safety or ergonomics, or both. The results were as follows:

a. Access to ergonomics specialist: 3(16%)

b. Access to health and safety specialist: 4 (21%)

c. Access to both ergonomist and health and safety specialists: 7 (37%)

d. No access: 5 (26%)

Total = 19 (100%)

Therefore, a total of ten participants were found to have access to an ergonomic specialist in their facilities (the sum of categories ‘a’ and ‘c’).

4.3.2 Nature of industrial engineer-ergonomist interaction

Of the ten participants with access to ergonomics specialists within their facilities, there were varying amounts of contact with these specialists. Ergonomics specialists were employed as permanent staff or external consultants. When they were full time employees for the company, participants had frequent, occasional, and rare contact. Participants are broken down by their amount of contact with ergonomics specialists as follows:

a. Frequent contact at work: 2 (20%)

b. Occasional contact at work: 2 (20%)

c. Rare contact at work: 2 (20%)

d. Contact with external consultants: 4 (40%)

Total = 10 participants with access to an ergonomics specialist (100%)

Only four of nineteen participants (21%) had frequent or occasional contact with an in-house ergonomics specialist.

4.3.3 The industrial engineer – ergonomist interface

The previous section (4.2) documented the impact of each element of the integrated model of the social ecology of industrial engineers on the practice of ergonomics, as reflected in interview data. Based on the subset of participants working with ergonomists, this section explores what characteristics of the interaction between industrial engineers and ergonomists influences the success of ergonomics interventions in the work system: perception of balance between industrial engineering and ergonomics goals and objectives; integration of ergonomics; and industrial engineer awareness of the services ergonomists can provide.

Perception of balance between industrial engineering and ergonomics goals and objectives

The most common reservation participants had about working with an ergonomist appeared to come from a sense that their objectives as industrial engineers may be unduly compromised. Participants with reservations perceived ergonomists as unwilling to work towards a common solution and expressed the desire for balance between the objectives of industrial engineers and ergonomists. For example, it was stated:

> “There's an element of a little stubbornness on the part of me, for example, as an engineer, because I'm taking also a different perspective of the issue. Because normally in ergonomics principles it’s very straightforward, but sometimes I'm the type of person who rationalizes things, whether we can bend a little to accommodate another important thing. So there are situations like that. If there were not situations like that then I would have no problem.”

This passage demonstrates the idea that by recognizing ergonomics objectives, other ‘important things’ may have to be sacrificed. One participant described this as *“a balance between loss and risk.”* This was illustrated in the following passage:

> “For example, you have to do a job rotation, so you satisfy the monotony of the people, doing job rotation for ten hours. You do this process, you do this process, you do this process, every two hours you interchange. We are doing it here. But on the other hand, in the perspective of quality, you are losing the traceability of your quality, because you don't know who failed on that process. The next time it’s a different person again. So, process perspective side, you have created so many variations in that particular process step, for the expense of solving the safety issue.”

However, industrial engineers felt that ergonomists were not willing to compromise to achieve this balance between loss and risk. When describing the relationship between industrial engineers and ergonomists, it was stated that *“always here safety prevails.”* Frustration was also occasionally expressed with the use of guidelines and limits in argumentation:

> “So, me, I'm alone, I have to argue, but sometimes still they'll prevail, because they'll invoke something, like a rule.”

Participants did not trust ergonomists to pursue the joint optimization of safety and productivity. As a result, some industrial engineers were reluctant to fully engage with ergonomists.

Integration of ergonomics into the work systems design process

Participants acknowledged the significance of the point in the design process when ergonomists joined a project. Primarily they supported early involvement of ergonomists in the work system design process. As one participant stated:

> “So if the ergonomist is involved from the beginning then they'll have the answers for [system users] and they'll understand how the station was set-up. So, it's better to have them involved the whole time.”

Participants also noted the lost potential when ergonomists were brought in at later stages, saying:

> “Often by the time that an ergonomist is hired and come in, somebody has already championed it from within. It either kind of never happens or it's already too late.”

Overall, it was felt that the expertise of ergonomists was best leveraged when they were involved from the very early stages of design.

Industrial engineers’ awareness of what ergonomists can provide

Finally, industrial engineers’ awareness of ergonomists’ abilities also significantly impacted the way they practiced ergonomics. The participants with the most functional working relationships with ergonomists appeared to have established guidelines dictating when they could use ergonomics assistance. For example:

> “I mean, I've been through a lot of ergonomics training too. So I've got a good feel for it before it even gets to the ergonomist. So, it's just when you get into secondary analysis, and they start using NIOSH and all these other programs that I don't use a lot. I let them do it because they work with it everyday.”

One participant created their own decision criteria, saying that if the ergonomics information they needed could not be found in a table, they would ask the ergonomist in their organization for assistance assessing risk factors. Others chose to ask for advice when they needed clarification on how to apply an ergonomics standard. Situations where industrial engineers were able to identify design problems best suited for detailed ergonomics analysis also appeared to be the situations were ergonomists were used most effectively.

Chapter 5
Discussion

Through the analysis of participants' work strategies and the ecological factors which influence them, this thesis describes how industrial engineers work in an organizational context, and the factors which affected this work. Key findings with regard to work strategy, organization design, awareness and trust, role ambiguity and globalization are discussed and implications are considered. Finally, recommendations for key stakeholders, such as system users, managers, ergonomists and industrial engineers themselves are made.

5.1 Strategy

Participants used a wide range of tools, from both industrial engineering and ergonomics (see Table 4.1: Tools reported in preliminary survey of industrial engineers, p. 34), in diverse and flexible ways. Participants often combined tools they were familiar with, and requested or created new tools and methods when they felt it would assist them in their work. They held pragmatic attitudes toward tools, not using them because they were available or recommended, but only when they saw the specific benefits to their work. Therefore, introducing new tools for work system design, such as more complex ergonomics tools, would not necessarily be effective as an independent step to improve the integration of social and technical systems. If ergonomics and positive work system design outcomes are supported from an organizational perspective, as research suggests (Badham & Ehn, 2000; Broberg, 2007; Perrow, 1983), tools are more likely to be employed by individual industrial engineers in order to reach these expectations. Investing in organizational support of ergonomics has the potential to make the ergonomics tools already present in organizations much more effective than more sophisticated ergonomics tools introduced without providing the proper organizational support.

Strategies related to organizational navigation also varied. All participants used formal and informal methods, depending on the situation and personal preference. In many situations informal tactics, such as frequent, informal interaction with system users, were established among participants as best-practices for industrial engineering work. Dow (1988) describes this as the coactivational formation of organizational structure. In coactivational development, organizational structure is created and maintained through a bottom-up process. As tasks are repeated recurrently, patterns of interaction emerge. These patterns are then established as the structure of the organization and function the same way as formally developed organizational structures. However, informal structures must be well integrated, observed, and respected by all stakeholders in the organization to function correctly. Based on participants' desire for management intervention in ensuring design ideas are properly implemented and maintained, power and authority over work systems appears to be an area where more formal intervention may be required.

Learning to navigate both the formal and informal structures of organizations is a strategy that is often recommended for ergonomists (Badham & Ehn, 2000; Broberg & Hermund, 2004; Hasle & Jensen, 2006; Jensen, 2002). Industrial engineers could be considered a resource on organizational dynamics for ergonomists entering the system, assisting them in this role. As well, experience navigating organizations to achieve their goals and objectives could be helpful to industrial engineers incorporating more ergonomics into their role. Holden et al. (2008) suggest specifically tailoring all information about the design process for delivery to different groups within the organization, such as using language and terminology familiar to the audience and framing suggestions in terms of the goals and objectives of each specific group.

Industrial engineers had many styles of interacting with system users and system designers, based on how they interpret their respective roles in the design process. Some of these approaches resulted in close contact with system users. This is significant as it may help address the many problems that have been attributable to isolation of designers from implemented work systems (Broberg, 2007; Helander, 1999; Neumann et al., 2009; Perrow, 1983), and designing portions of the system without considering their ultimate integration (Neumann et al., 2009). Results show that industrial engineers do have contact with system users, and therefore access to feedback that may improve the design of work systems. The fact that is not reflected in prior research indicates that this feedback may not be applied as productively as possible. Ergonomists may be able to leverage any existing dialogue between industrial engineers and system users when attempting to improve the integration of ergonomics in work system design, perhaps achieving gains associated with participatory ergonomics (PE). The team member and client roles described in the results on stakeholder interaction (see section 4.1.3) demonstrate industrial engineers are striving for a participatory mode of design, supporting the power and involvement conditions required for successful PE (section 2.4 Participatory ergonomics, p. 14). Further development of these techniques and attitudes could be beneficial in creating a more holistic approach to work system design.

5.2 Organization design

Results generally indicated that the social ecological model, the systems model for work system design, and socio-technical design theory are useful for characterizing the work practice of industrial engineers. Participants were cognizant of the influences of macro- and mesosystem effects on their work. Industrial engineers appear to be aware of the limitations of their organizational position and the overall design process, but are generally not in a position to change this. However, those who do have this authority, such as managers, could work to apply these observations to improve the work design system outcomes under their supervision.

Management support is considered an important contributor to the success of ergonomics initiatives within organizations (Holden et al., 2008; Jensen, 2001; Perrow, 1983). Results show this is also the case for industrial engineering projects. Several participants cited the importance of management backing up their decisions and supporting their efforts to the effectiveness of their work. Also, similarly to ergonomists (Neumann et al., 2009; Perrow, 1983), industrial engineers were affected by their placement in the formal organizational structure, which limited their proximity, access, and authority they had over the system they were working on. For example, participants observed emergent design problems that can result from early design decisions which do not accommodate good work system design, and several participants cited examples of design decisions made at early stages in the process negatively affected their ability to achieve their design objectives. These problems are well documented in existing literature (Broberg, 2007; Burns & Vicente, 2000; Neumann et al., 2009; Perrow, 1983) and are a violation of the socio-technical principles of boundary location, and power and authority (Cherns, 1987; Pasmore et al., 1982). Holden et al. (2008) addresses these issues in the context of change management, stating employees should be provided with the skills, training, freedom, information, financial support, and tools they need for their jobs. Finally, participants faced obstacles from the lack of ‘support congruence,’ the fit between organizational incentives, rewards, and boundaries and the goals of the system, in their organizations. The effectiveness of industrial engineering practice may be improved by ensuring incentives and rewards for both system users and system designers are based on indicators under their control and support positive work system design outcomes.

Overall, it appears it would be more successful to use an organizational or systems approach rather than to target individual actors when attempting to improve the effectiveness of industrial engineers; reaffirming existing literature suggesting this is necessary for ergonomics success (Broberg, 2007; Moray, 2000; Neumann et al., 2009; Perrow, 1983).

5.3 Awareness and trust

The ability of industrial engineers to do their daily work was affected by system users’ and management’s awareness, knowledge and understanding of industrial engineering. Kegan & Rubenstein (1973) discuss the importance of trust in working relationships to employees’ desire to improve, and willingness to give and receive information within the organization. Lack of trust between co-workers can affect motivation to work toward shared goals and coordinate their efforts with others (Dirks, 1999). This supports participants’ statements suggesting until stakeholders appreciate the benefits of industrial engineering interventions and a rapport is established, industrial engineering work will be limited in its effects.

This resistance may be attributable to the resources these stakeholders must make to facilitate changes in the work system. Both managers and system users were asked to trust industrial engineers in domains that were essential to their success at work. Management allocated budget, man-power, and their own time, all of which could be put towards other projects. Even more significantly, system users had to trust industrial engineers to provide a safe, comfortable and fulfilling job and to ensure their job security, often while personally investing themselves in change efforts. Building awareness about ergonomics issues and establishing trust between work system stakeholders has the potential to reduce this resistance to work system design changes and benefit all parties. One way to address this could be through organizational development and training programs such as team-building, sensitivity training, and management by objectives (Jones & George, 1998; Kegan & Rubenstein, 1973).

A similar dynamic was observed in discussions of the effectiveness of ergonomists in the organization. The relationships between industrial engineers and ergonomists were reported as most successful when system stakeholders, especially the industrial engineers themselves, trusted the ergonomist with resources and support, and had trust and understanding of ergonomists' ability to utilize these resources to their benefit. The clearest obstacle to relationships between industrial engineers and ergonomists were seen when industrial engineers did not trust the ergonomist. This lack of trust appeared to come from the feeling that the industrial engineers' objectives would be sacrificed and their input would not be considered. As a result they appeared to become more territorial over system decisions and less receptive to the ergonomists' proposals. Relationships were most successful when industrial engineers and ergonomists established cooperative relationships, rather than attempting to coordinate work done separately by each discipline.

In order to achieve the best possible results for industrial engineers and ergonomists working together, a collaborative mode of interaction may be most appropriate. Coordination, cooperation, and collaboration could be considered a spectrum of ways for designers to work together, ranging from most individual to most interdependent. Collaboration aims “to achieve collective results that the participants would be incapable of accomplishing working alone,” and is most appropriate in complex systems (Pollard, 2005), making it ideal for integrating sub-systems in design. Pollard (2005) provides suggested preconditions, tools, and enablers for cooperation, coordination, and collaboration respectively. Training in collaborative techniques, appointing facilitators, establishing shared objectives, open communication, and a trusting, respectful environment may be beneficial to improving the success of joint ventures between industrial engineers and ergonomists. However, substantial commitment is needed from system designers in order for collaboration to be feasible (Pollard, 2005).

Although most participants would not argue that the health and well-being of system users should be top priority, the incentives and rewards built into their job description require them to focus on other objectives, such as productivity, efficiency and quality (Perrow, 1983). When working with industrial engineers, ergonomists must be sensitive to the way their jobs are designed and take care that ergonomics initiatives do not directly contradict these objectives. Ergonomists could reduce resistance from industrial engineers and other system designers through increased understanding of their objectives and by learning to justify ergonomics initiatives in relationship to these goals (Broberg & Hermund, 2004; Burns & Vicente, 2000; Mekitiak et al., 2008; Wulff et al., 1999b).

In general, building awareness and trust surrounding industrial engineering through the above suggestions, appeared to facilitate a process of ‘setting up’ the organization for ergonomics change. Creating awareness and building trust with system users, other system designers, and management can reduce the work industrial engineers must do when attempting to implement ergonomics principles by establishing buy-in and organizational support. For example, once management is convinced of the system benefits of applying ergonomics they were more likely to allocate resources to subsequent projects in many cases. As well, system users can be prepared with the knowledge and awareness they need to make suggestions or complaints about work system conditions to industrial engineers and management.

5.4 Role ambiguity of industrial engineer

Role ambiguity can have serious effects for both the individual and the organization, leading to stress (Bliese & Castro, 2000; Ivancevich & Donnelly Jr, 1974; Rizzo et al., 1970), dissatisfaction (Abramis, 1994), disinterest, and less innovation at work (Ivancevich & Donnelly Jr., 1974; Rizzo et al., 1970; Steers, 1977). As a result, it increases the risk of work-related ill health for both industrial engineers, and system users. In the case of industrial engineers, participants often indicated that their role in the organization was not well defined. To do their work they had to navigate between the goals of management and system users, often feeling ‘caught-in-the-middle’ of the two groups. In addition, their role within the work system design process varied from a leadership role to a more passive consulting role.

Results show role ambiguity is likely to occur between industrial engineers and ergonomists due to the relationship between the two disciplines. Industrial engineering and ergonomics both aim to optimize the performance of work systems but emphasize different methods for achieving this. When participants discussed using ergonomics principles in their work, they did not always label it as practicing ergonomics. Generally, when ergonomics principles were applied to improve user well-being, it was described as ergonomics work; however when the same or similar methods were used to improve productivity or efficiency in the system, it was usually considered to be industrial engineering. On an individual level, when the roles of ergonomists and industrial engineers were not clearly defined, industrial engineers could be confused about when to perform ergonomics tasks themselves, and when to delegate these tasks to an ergonomist. In some situations, participants hesitated to take on ergonomics related tasks because they felt it was not in their realm of responsibility.

Ivancevich and Donnelly (1974) suggest role clarity can be improved through better communication and consideration of expectations by managers to employees, and providing more information and specifications about work tasks. In addition, mapping the work system design process may decrease role ambiguity by clarifying to system designers who does what, informing system users who to approach with questions and concerns, and facilitating dialogue about roles and expectations (Neumann et al., 2009). It may also serve to identify common goals and objectives between separate groups, such as industrial engineers and ergonomists. Specifically, ergonomists could improve their collaborations with industrial engineers by creating a sense of definition of their role and awareness of the services ergonomists can provide. Ergonomists should demonstrate the functions they perform as clearly as possible and give advice on when those services would be of most benefit. When they succeed, industrial engineers will know when to call in ergonomists and when to rely on their own expertise.

5.5 Globalization

It was found that many of the macrosystem factors influencing industrial engineering work may be linked to globalization, such as availability of labour, lack of job security, immigration, differing attitudes about work-life balance, and differing interpretations of health and safety regulations. Globalization has increased the distribution of engineering work internationally, while bringing system designers from diverse backgrounds together on common projects and design teams (Carayon, & Smith, 2000). Previous research has shown that engineers in different cultures work differently (Adams, 2007; Lynn, 2002); however, due to globalization, many engineers trained in these different traditions are working together regularly making collaboration and communication more difficult. As well, attitudes about health and safety and interpretations of regulations are likely to differ among designers with training and working experience in different cultures. Finally, in addition to creating challenges for collaboration between designers, globalization also makes it more difficult to identify and characterize system users (Moray, 2000). Regional and cultural differences create new criteria and constraints for work system designers, making it more difficult to predict the outcomes and potential risks associated with design decisions (Bao, 1997).

5.6 Recommendations

Based on the discussion above, several recommendations for improved work system design practices can be made. These recommendations focus on the mesosystem level, the industrial engineer-management interface, the industrial engineer-system user interface, and the industrial engineer-ergonomist interface. The macrosystem has been excluded as changes at a societal or cultural level are unlikely to be feasible or directly actionable by individuals. Focus is on organization design and structure, education, training and communication. Recommendations are directed to specific stakeholders as appropriate and are summarized in Table 5.1.

When reviewing recommendations, it was noted that many of the ideas recommended for industrial engineers closely followed accepted guidelines for ergonomists working in organizations. For example, the need for management support, involvement of system users, establishing awareness and understanding of ergonomics throughout the organization, and applying ergonomics as early as possible in the design process are recommended in literature addressing workplace ergonomics (United States General Accounting Office, 1997; Occupational Health and Safety Council of Ontario, 2007) and also appear to be applicable to industrial engineers. This similarity may be the result of the correspondence between the goals and objectives of industrial engineering and ergonomics and similarities in organizational position. Like ergonomists, industrial engineers were often sent in to do ‘improvements’ to an already existing system, and did not always have formal organizational influence over the work system they were designing.

Table 5.1: Summary of recommendations for improved integration of social and technical systems in work system design

Area of Focus	**Recommendations**
Mesosystem	**Managers:** Provide work system designers (particularly industrial engineers) proximity, access and authority to change the systems in which they are implementing changes. Support the integration of work system design considerations into the early stages of the design process. For example, industrial engineers could be involved directly or work system design related training and design criteria could be provided to system designers at all levels (i.e. design for manufacturability). Ensure support congruence. Consider the effects of all incentives and rewards on work system design outcomes beyond the mircosystem level. For example, providing rewards and incentives for cost-savings may potentially encourage employees to neglect other work system outcomes, such as adverse human effects. Provide a venue for system users to voice concerns about ergonomics issues they observe on the job, such as a regular meeting, a suggestion box, or a clearly recognizable individual to approach. Encourage system users to use this venue to make suggestions proactively, and not just react to existing problems. Introduce organizational development programs, such as team building or general meetings, and establish ergonomics training and education programs in order to increase awareness of ergonomics throughout the organization and improve trust and understanding between all groups in the organization. **Managers and Ergonomists:** A systems approach to changing work system design outcomes is likely to be more effective than targeting individual actors. Interventions on an organizational level (addressing structural barriers, building awareness and trust, introducing training and education, etc.) should be prioritized over direct interventions to industrial engineers.
Industrial engineer-management interface	**Managers:** Learn about industrial engineering and ergonomics principles, particularly how they can serve business objectives and strategies. Consider how to position industrial engineers and ergonomists most effectively within the organization. Provide clear information about the role of each stakeholder in work system design. This could be done through use of a process map of the design process to facilitate dialogue and coordination between groups.

	Industrial engineer: Improve communication with management about work system design concerns, and relate design concepts to organizational strategy and objectives. For example, ergonomics aspects of a project can be aligned with business strategies such as reducing operation costs, operational efficiency (including eliminating non-value adding activities), quality improvements, product design, and employee satisfaction and loyalty.
Industrial engineer-system user interface	**System Users:** Learn about the ergonomics risks that may occur in your work station and how to effectively communicate ergonomics comments or concerns to industrial engineers, ergonomists, and/or managers. **Industrial engineers:** Learn to use system feedback to learn about ergonomics issues affecting system users. For example, in addition to direct feedback from system users, injury data, absenteeism, worker turnover, and changes in quality can all indicate a need for ergonomics improvement in the work system. Improve communication with system users about work system design concerns, and relate design concepts to the goals and objectives of these groups. For example, regularly observe the work system in person, attempt to understand and empathize with potential concerns system designers may have, understand the constraints of their job, and/or clearly explain the objectives of industrial engineers within the organization.
Industrial engineer-ergonomist interface	**Ergonomists:** Try to identify and understand organizational dynamics and customize arguments and evidence supporting work system design changes to the goals and concerns of specific stakeholders, especially industrial engineers. Learn about the goals and objectives of industrial engineers. Try to understand them thoroughly enough to align ergonomics suggestions with these objectives. For example, attend to productivity objectives. Investigate any ergonomics related tasks that are part of industrial engineers' work routine. For example, leverage any existing interaction between industrial engineers and system users to create opportunities for collaboration and participation between the two groups. **Industrial engineer:** Improve communication with management, ergonomists, and system users about work system design concerns, and relate design concepts to the goals and objectives of these groups. **Ergonomists and Industrial Engineers:** Work to establish a collaborative relationship for work system design through increased interaction, and establishing shared goals and objectives for the system.

5.7 Methodological discussion

Mays and Pope (2000) state that the quality of qualitative methods can be assessed using the same concepts as in quantitative research, so long as they are interpreted with the goals of qualitative research in mind. Their definitions of validity and relevance have been used to asses this project.

5.7.1 Validity

Validity describes the lack of error in research (Mays & Pope, 2000; Patton, 2002). It can be increased through clear reporting, reflexivity by researchers, addressing negative cases, and fair dealing.

Clear Reporting

The importance of clear reporting to minimize the effects of researcher bias and assumptions on results is frequently emphasized in qualitative methods. It improves validity by allowing the reader to judge the research results independently (Janesick, 2000; Patton, 2002; Silverman, 2000).

Every effort has been made to report the methods used in this project clearly, accurately and comprehensively. Unfortunately, due to the proximity of the author to this project, it is possible that some details relevant to the readers' understanding may have been overlooked. As well, certain topics covered in the interviews were not reported and are intended to be covered in future research.

Reflexivity

In theory, most qualitative research is inductive, attempting to approach problems with no prior assumptions. However, in practice this is nearly impossible as researchers well versed in their field tend to know the existing theories related to the phenomena under study (Patton, 2002). Thus, it is important for researchers to be self-aware and upfront about any personal or intellectual biases which may influence their interpretation of results.

The researcher taking the lead role in this project has a background in industrial engineering, specializing in human factors. Strong identification with the participants and their professional identity was inevitable. In addition, the researcher’s personal belief in the importance of ergonomics in organizations is another potential bias.

Countermeasures included balancing researcher bias through the team-based approach used. Experts in an array of disciplines were integrally involved throughout the research design, analysis, and interpretation.

Negative Cases

Negative cases are instances in the data set which may contradict emerging theories about the research questions. Because the analysis has been presented using dimensions and ranges of behaviour to describe phenomena observed, there is little opportunity to completly refute the resulting frameworks. Although not all participants directly commented on each element of the analysis, the researcher is not aware of any explicit negative cases. It is possible that the semi-structured nature of the interviews may have contributed to this general consensus. Different lines of questioning across the interviews meant there may not have been the opportunity for each participant to comment directly on each element of the analysis. Counter examples may exist and should be attended to in future work.

Fair Dealing

Fair dealing required researchers to ensure that views of one particular group are never claimed to represent the solitary truth about a situation (Mays & Pope, 2000). Any conclusions drawn in this project are based on discussions with a small percentage of the industrial engineers currently practicing in Ontario and thus any statements referring to the profession of industrial engineering as a whole are potentially misleading. This issue was partially addressed by focusing the study on industrial engineers, and no other work system designers. Fair dealing is increased by allowing accurate reporting of whose perspective is actually being portrayed in the data.

5.7.2 Relevance

Relevance refers to the degree in which the research adds to knowledge or increases the confidence in existing knowledge of a topic. It also considers the degree to which findings can be generalized beyond the specific setting of the study (Mays & Pope, 2000).

Knowledge

Data was collected to support ecological and systems-related models of the work system design process. It was shown that the organizational conditions considered favourable for ergonomists could extend to another group of work system designers, namely industrial engineers. This is interesting because it reframes the issues of application of ergonomics as a symptom of the emergent nature of work systems, and creates the possibility for exploring the applicability of industrial engineering strategies to the work of ergonomists. Finally, new knowledge was generated about the practice of industrial engineers, a topic which does not appear to be well represented in existing literature (Trevelyan & Tilli, 2007).

Generalizability

Generalizability of results is limited by the sample of volunteers. It is possible that industrial engineers of specific industries, regions, levels of experience, among other factors, could skew results. In addition, because this study relied on volunteers, participants may reflect certain personality traits more than the general population of industrial engineers in Ontario. For example, participants may be more motivated on the job, or more interested in professional development than other groups. It is also of note that these results are attributable to the profession of industrial engineers as a whole and cannot necessarily be used to predict or describe the specific behaviour of individuals.

5.8 Future work

In the future, further research is recommended to both confirm and extend the results of this study. Topics discussed included aspects of relevance to the larger research team involved in the project and the resulting volume of interview data collected was too large to be analyzed completely in one thesis. Therefore, further exploration of the data is recommended. In particular, more analysis is necessary of the more technical aspects of industrial engineering work, including the criteria and constraints for their designs and prioritization. This will give more specific insight into the day-to-day work processes of the participants. Analysis of how projects are prioritized may give insight into how management allocates resources and how work system designers can frame new projects to successfully gain management support.

In addition to more in-depth analysis of the industrial engineering interviews, there is the opportunity for comparison of these results with the data collected through interviews with ergonomists in an earlier phase of the study. Comparing the insights of work system designers representing the social and technical systems adds additional context to the results and creates a clearer picture of the overall work system design process.

Further, new data could also be collected to verify and expand on the results presented here. Similar studies could also be conducted with additional system stakeholders, such as managers, system users, or other disciplines of engineers, who have been shown to influence the work system design process. This would serve to increase a sense of fair dealing by ensuring that the perspectives of many groups are accounted for. Also, conducting interviews with a broader sample of industrial engineers would act to increase relevance and validity of results by increasing generalizability and searching for negative cases.

While the intention of this research was not to produce a verified and exhaustive description of working practice, further work could be done to confirm and extend the analysis framework presented. In the short term, a small sample of industrial engineers could be solicited to review the findings and comment on the degree of correspondence with their own professional experience. In the future, case studies could be conducted within various organizations to test the robustness of the analysis. This would also serve to extend the theory as new insights are accumulated and negative cases are uncovered. Finally, quantitative studies could be devised to test specific hypotheses emerging from the research.

Chapter 6
Conclusion

Flawed work systems result in ill-effects for the well being of individuals, businesses, and society. These flawed systems may be attributable to a gap in work system design practice which prevents the joint optimization of social and technical sub-systems within an organization. This thesis aimed to address the issue of sub-optimal work system design through a series of interviews with Canadian industrial engineers. By understanding the way industrial engineers work in an organizational context and the ecological factors which affect their practice it was expected that recommendations could be made to better facilitate the application of ergonomics by industrial engineers.

The first aim of this thesis, to understand how industrial engineers work in an organizational context, was investigated through analysis of work strategies; including tool use, organizational navigation, and stakeholder interaction. Results showed that industrial engineering practice consists of a wide range of strategies, adapting to surrounding conditions rather than focusing on specific tools, methods, or tactics. How participants did their work was influenced by many factors in their working environment, investigated through the second aim of the thesis: to identify ecological factors which impact industrial engineering practice, particularly in regard to ergonomics. The effects on work system design practice were described using an ecological model composed from existing literature. Macrosystem factors, mesosystem factors, and the interactions between industrial engineers and management, system users and ergonomists all influenced the effectiveness of industrial engineers in their organizations. Finally, immediate and long-term solutions for improving the application of ergonomics in the work system design process were sought. It is recommended that awareness of ergonomics and work systems design issues be established throughout the organization, and industrial engineers work to improve trust, communication, and collaboration with other stakeholders. It appears that changes in work system design would be most effective if approached systemically. In the long-term, it is recommended that organizations be designed with work system outcomes in mind. For example, involving work system designers in the early stages of the design process, establishing rewards and incentives which support positive work system design outcomes, and providing industrial engineers and ergonomists organizational proximity and access to system users.

These findings and recommendations comprise a preliminary assessment of factors relevant to the effectiveness of work system design by industrial engineers. This knowledge may be built upon to establish standards and best practices for facilitating proper work system design and application of ergonomics in organizations. It is recommended that an organizational approach to changing work system design be further investigated. Talking to additional stakeholders in the process, such as managers and system users, is likely to uncover more details about the conditions necessary for consistent, long-term changes in the application of ergonomics in organizations.

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Appendix A: Verbal Consent Script

Hello. Thanks for agreeing to speak with me today.

Before we begin, did you get a chance to read the ‘Participant Information’ sheet?

First, I need to review some important points about your participation.

- This is voluntary. You can stop the interview at any time or choose to not answer specific questions.
- I’m recording and transcribing our discussion, but any identifying information will remain confidential. Anonymous excerpts from this interview may be included in the thesis or publications to come but will be presented in a way that removes any contextual or potentially identifiable information.
- Also all information will be kept on secure computer systems and your name will not be stored directly with any audio or transcript files.
- After the interview, you may request a copy of the transcript, which you can to modify or add to before analysis.
- Finally, this project has received clearance through the Research Ethics Board at Ryerson University.

Any questions?

I’ll start by giving you a brief review of my project, and then we can get started.

Appendix B: Interview Schedule

Begin with ‘verbal consent script,’ study recap, and answering questions.

Theme	Research Question	Script
About the Participant		
Who	RQ1. Who is in our sample? (specific demographics covered by email survey)	First, I’d just like to confirm that your employer is _______? And your job title is _______? Can you describe your job a little bit? If employee: Organization: Can you tell me a little about your organization? - In terms of sector, how would you classify your organization? - What kind of work does your company do? (e.g. office work, industrial, etc.) Relationships: Who do you usually work with? … - Who do you report to? What department do you work in? (formal structure) - Are you part of an informal team? (informal structure) - What is your relationship with users, managers, operators, etc.? If consultant: Clients: Can you tell me briefly about your clients? - How many clients would you usually have at once?

		- What kind of work would a ‘typical’ client engage in? (e.g. office work, industrial, etc.) - Generally, how large are the companies you work with? - Do you have clients that **don’t** match this profile? Relationships: Who do you usually work with? - Do you report directly to the client? - Who is your closest contact at the client’s company? What about within your org.? - Who do you report to? What department do you work in? (formal structure) - Are you part of an informal team? (informal structure) - What is your relationship with ergonomists, operators, etc.? If long-term consultant: - Explore relationships from ‘consultant,’ ‘organization,’ ‘employees.’
Work processes, tools/methods and environment Note: Change order based on ‘Role’ conversation; Probe for human factors when appropriate		
Design Process	RQ2. What is the general design process that takes place within the organization?	I was hoping you could give me some context for your work before we go into more detail. Can you describe your company’s development process and where you fit within it? - Who do you have to coordinate with on a project? - Are there other departments/teams involved? - Problem analysis/Pre-study? Conceptual design? System design? Development? Manufacturing/Industrialization? Production? Maintenance/Quality assurance? Etc.

Methods/Tools	RQ3. What is the interviewee’s role within the organization? RQ4. How does the engineer do their work? (including tools, methods, feedback, follow-up, etc.) RQ4.1 What is the most common flow of information through the organization?	Now, let’s talk in more detail, about what do you DO in your work. How would you describe your role in the organization? - Types of work - Duties and responsibilities - Responsibilities extraneous to usual design tasks that take up time? How do your projects get initiated? How do you get involved in the project (personally)? To what degree are you in control of your projects? Are you supervised? How are projects prioritized? - How are health and safety projects identified? - What factors would you include in a cost-benefit analysis? What information do you collect at the beginning of a project? What is the source of this information? - productivity goals, system goals, operational challenges - requirements/criteria for design - problems, complaints from prior projects - restrictions - operator complaints, health and safety comments What are the key constraints on your designs? How do you determine these? Now, let shift to the information that you **provide**. In your e-mail, you listed several tools/methods from your toolbox, let’s run through the tools you draw on and the information you gain from them (refer to email survey). In what circumstances do you use that tool? Why? How does it fit into sequence with the other tools you listed? (order of use if they are both applied to the same type of project) *(Note: choose relevant probes based on tools sent ahead of time, iterative for each tool)* (Consultants: Explore a ‘typical’ project or two, if possible, and focus on those specific tools.) Do you use it in combination with another tool, method?

		Advantages and disadvantages? What’s the most useful **information** (or indicators/outputs) you get from this tool? Source: Can you describe how you came to be using this tool (for your work)? Data sources for the tool? Standards: Is there a guideline or a recommendation level associated with it that you rely on? Usage: Would anyone else use this tool? Resources: What resources do you need to use this tool? Training, preparation, field work, post-processing (per application) Time, cost, materials, social support or labour After the final tool: Now, we’ve gone through a number of tools…. - Selection process: Generally, how are these tools selected? Is it just you, or do any other stakeholders participate in the selection? As you move through a project are there any standards you use to guide your design decisions? Indicators to assess the success of design concepts? How do you know that your work on a project is done? What is your end point in the process? Who signs off on new designs/who do you have to convince? (information uptake/persuasion) - Are there characteristics or requirements for your design that are more valued by the people you are convincing? - What is the attitude toward designs that prioritize other aspects of the design? - Safety element to the sign off? - How often are changes requested? Once the project is complete what kinds of feedback do you receive? Do you follow up to see how your designs are working once they’re implemented?

Human Factors

Note: Hopefully some of this will come up in earlier sections

Human Factors/ Ergonomics	RQ6. How is the operator considered in the design process? (i.e. safety concerns, skill sets, choosing heights, reaches, grouping tasks, work organization, designing social system, etc.)	Okay, so now that I know some of the details of how you work, we're heading into the last stage of the interview. At this point I just want to shift gears a bit and focus on human factors and how user well-being is considered in the design process. Is there a formal process for bringing health and safety into design at your company? (If so describe. If not, informal?) - Formalized guidelines or design requirements? - Specific person in charge/accountable for 'work environment'? - Health and safety committee (is there an engineer on it?) How does this play out in practice? How does it impact your work? Beyond safety considerations, how are users considered during the design process? <Based on conversation classify them by work station design/tool and equipment design, Work environment design, work organization>. Probes depending on type of work: Work station/tool and equipment design - Fit - Reach - Adjustable - Design for extremes - Anti-slip - Standing mats - Vibration - Maintenance - Usability (intuitive to use) Work environment design - Lighting - Ventilation - Vibration - Humidity/temperature - Noise levels

		Work organization - Pace of work (machine driven? Incentive driven? Operator driven?) - Variety of work/job rotation? - Amount of material handling? - Shifts? - Workload? - Facility layout What is your sense of the role of human factors specialists and the services they provide? Have you ever been in a situation where you would’ve liked to work with a human factors specialist? - What kind of project was this? - What specific concerns, (tasks?) did you work on with this person? (My thought here is to distinguish between the project broadly and more specifically how they related to one another.) - What are your impressions on how this worked out? What is your opinion of the impact of <improving worker well-being and safety> on performance? (economic, quality, productivity, etc.) - trade of performance for HF or mutual benefit of improving both at once
Human Factors/ Ergonomics Integration	RQ7. Where can ergonomics best be accommodated in the design process?	Alright, and now just to close this section, do you have any suggestions as to how <user needs, human factors, ergonomics, health and safety> could be better addressed in design at your organization? - Pros and Cons of current situation - Barriers and Limitations? - Opportunities for improvement/innovation/facilitators How could human factors better support your work? Is there a better way to present this information?

Closing		
Assessment	RQ8. How does the engineer feel the design process could be improved? Are there any changes they would like to see?	How could your job be improved? What aspects do you like/dislike the most? - Pros and cons of current situation - Barriers and limitations? - Opportunities for improvement/innovation/facilitators? - What qualities do you feel are important?
Closing		Okay, we've finished the interview. Is there anything you'd like to add? If I have any additional questions, would you mind if I gave you a follow-up call? Again, just to remind you: - You will receive a copy of the transcript. Please feel free to make changes if you wish. - Also, once we're finished, a project report will be sent to you. - Again, if you have any questions, please contact me Okay, that's it! Thank you. Good bye.

Appendix C: Pre-interview email survey and results

The following email was sent to participants prior to their interview.

Hello <participant>,

We spoke <date> about your participation in our study on work system design and industrial engineering. Before the interview (<interview date and time>), I would really appreciate it if you could fill in the short survey at the end of this email. It is intended to help me prepare for the interview and make the most valuable use of your time when we talk. Simply reply to this message and type in your answers.

Should you have any questions, please feel free to contact me. I look forward to our discussion.

Best regards,

\-----------
EMAIL SURVEY

A > BACKGROUND
- Gender:
- Age:
- Education (area of study, degrees):
- Professional certifications (e.g. PEng):
- Professional Associations (e.g. IIE):

B > WORK
- Job title:
- Job status (employee, consultant, self-employed):
- Total years of engineering experience:
- Total years of experience in this position:
- Employer/Dept.:
- Size of employer (no. of employees):
- Total no. of engineers at workplace (if known):
- Total no. of ergonomists at workplace (if known):

C > WORK SYSTEM DESIGN TOOLS, EQUIPMENT AND METHODS

Please list the work system design tools, equipment and methods you use when designing or evaluating a work system. Order the list from 'most used' to 'least used'. Please be as complete and accurate as possible.

For example: software (including CAD packages, simulations, stats packages, scheduling tools, layout tools, etc.) methods (i.e. Time Study, FMEA) physical tools (i.e. measuring tape, stopwatch, etc.) charts and notations (spaghetti diagram, Business Process Redesign Notation, etc.)

Tools, Equipment and Methods (including reference materials):
1.
2.
3.
4.
5.
Others:

D > CONTACT INFORMATION

Preferred Phone #:
Preferred Email:

Thank you for your assistance.

Appendix D: Sample Demographics

	M/F	Age	Education	Associations	Certifications	Experience – Total (years)	Experience - current job (years)	Company Size	# ENGs	#ERGOs
ENG-01	M	36	MEng INDY	IIE	PEng, Six Sigma Black Belt, Certified quality engineer (ASQ)	10+	2+	350 at facility, 1800+ worldwide	11 at facility, 60+ worldwide	2 (I.E.'s)
ENG-02	F	26	BASc INDY	IIE	N/A	3	1	~200	15	0
ENG-03	M	47	BASc, MBA	IIE	PEO, CMA, PEng	20	7	300+	1	0
ENG-04	M	25	BASc, INDY, MBA in progress (April 2009)	N/A	PEng in progress	2 or 3	1 month	10000+	unknown	unknown
ENG-05	M	47	MSc INDY	Former member of ASQ and APICS	PEng in progress	20	15	200	11	0
ENG-06	M	26	BEng, INDY	PEO	PEng in progress	2.5	1 month	800	unknown	unknown
ENG-07	M	29	BEng INDY	IIE	N/A	2	0.5	12 500	70-80	2 or 3
ENG-08	M	25	BASc, INDY	IIE	N/A	1.5	2	3	1	0
ENG-09	M	34	BASc INDY, MASc in progress	KMDI	PEng	10	2	60 000	4	0
ENG-10	F	24	BASc, INDY	N/A	N/A	16 months	1 month	138 000	unknown	unknown
ENG-11	M	44	BSc Mech. Eng	PEO, PMI	PEng, PMP	20 years	2	5000 worldwide	approx 35	0
ENG-12	M	38	BASc, INDY, MSc in Ergonomics	N/A	Registered Professional Engineer registered in Alberta since 2004	10 years	2 years	65000	?	?
ENG-13	M	39	BEng, INDY	PEO, IIE, PLOG	PEng, P.Log, LEAN SCM - Green Belt	15yrs	7yrs	45000	1800+	3+
ENG-14	M	44	Metallurgical Engineering Technology, Bachelor of Technology -INDY, Bachelor of Education	N/A	N/A	16yrs	15 years	3000 (at facility)	approx 120	2
ENG-15	F	30	BASc. INDY	N/A	PEng	5	0.5	11000	at least 30	unknown
ENG-16	F	28	BASc INDY, M.Eng	N/A	N/A	4.5	2.5	5000	unknown	unknown
ENG-17	M	44	BASc INDY	N/A	N/A	20 yrs	15yrs	3500 (at that facility)	50?	1
ENG-18	M	47	BSc INDY	IIE	N/A	15+ years	15+ years	8000	200	2 or 3
ENG-19	F	45	BASc INDY, MASc, OR	ex-IIE, AME	PEng; Certified Lean; Trainer (Dana University Internal Training, Dana Corp.)	17	5 months	1200	12 Manu-facturing, 8 SMT	2

Appendix E: Coding Scheme

	CODE	DESCRIPTION/NOTES	RELATED CODES
A.	**Participant profile (store in spreadsheet, not NVIVO)**		
1)	**Country**	Canada or Sweden	
2)	**Province**	Canada Only	
3)	Gender **M/F**	Male (M) or Female (F)	
4)	**Age**	Number of years	
5)	**Education**	Formal education (BASc, etc.)	
6)	**Associations**	IIE, PEO, PMI, etc.	
7)	**Certifications**	PEng, CPE, PMI, etc.	
8)	**Experience (total)**	Total years of engineering experience, measured in years	
9)	**Experience (current position)**	Length of time in current position, measured in years or months	
10)	**Job title**		
11)	**Department**	What department they are part of in organization	

12)	**Employer**		
13)	Company **size**	Number of employees (sometimes distinguished between company as a whole and number of employees at participant's particular site)	
14)	**Job status**	(employee, consultant, self-employed) Meant to be equivalent to the ergo code of internal/external job status Only 2 participants were not considered 'employee' (one consultant, one self-employed)	
15)	**Sector**	From NAICS list (government, light industrial, heavy manufacturing, various, etc.)	
16)	**# Engineers**	Number of engineers at facility	
17)	**# Ergonomists**	Number of ergonomists at facility	
	CODE	**DESCRIPTION/NOTES**	**RELATED CODES**
B.	**PROJECTS AND PRACTICES**		
18)	**Working relationships** (discussions related to organization structure around engineering or about specific instances describing working relationships; excludes future-oriented discussions of relationship building and HF integration) a. **General discussion** about relationships/ stakeholders	Lists of who they work with, sometimes includes job definitions for roles outside of IE, sometimes describes who is in what department, organizational structure Includes relations with customers (internal and external) Some union related comments Not too many detailed descriptions of relationships,	20. Scope of work/division of labour

	b. Management c. **Users** (Workers) d. Ergonomics and/or Health and Safety [**Ergo or H&S staff**] e. **Other** (specific groups rather than the general descriptions in 'A', for example 'Union' or 'Mechanical Engineer')	mostly just documents what relationships exist Descriptions of the roles of other people in the organization References to teamwork Issues: - relationships between groups vs. between individuals - who they relate to and how they do it	
19)	**Practices&Approaches** (***general*** comments about participant's practices ***unrelated to specific projects or tools***; comments regarding general tool usage, "how") a. **"Sizing-up" a problem** (level of analysis, example top-down vs. bottom up, problem definition) **b. Ergonomics&HF** **c. Other**	Information collected at different phases of the project, decision making, etc. **Catch-all for miscellaneous discussions that appear useful**	25. Priorities (how to prioritize is part of 'practice')
20)	***Scope of work&division of labour*** (structural and functional division of labour, diffusion of responsibility, general discussions about the kinds of work IEs engage in, including sectors and projects, "what")	Describes the domain or scope of work that is the responsibility of the IE, includes discussions about who is responsible for other tasks and general descriptions of organizational structure (vertical or horizontal) *Who does what*?	21. Role of IE

21)	**Role of IE** (how they see themselves, e.g. consultative, expert, facilitator, communicator, and how they think others see them, where they fit in the organization)	Include professional goals, impact of IE on different members of the organization (employees vs. management vs. clients, etc.) Almost all reflections on ‘industrial engineering’ or themselves as professionals are included here	20. Scope of work/division of labour 38. Future-oriented IE

22)	**Types of projects** (descriptions of specific projects) a. **New (products, line set-ups, etc.)** b. **Continuous improvement (Lean)** c. **Work station design** d. **Layout** e. **Work standardization** f. **Optimization** (resource allocation, capacity planning, etc.) g. **Ergonomics** h. **Other projects**	Specific process descriptions [16] describes overall processes related to IE projects, this code captures descriptions of specific projects May be some overlap between subgroups, potential to change divisions after some test coding Material handling is under work station design Process redesign and value-stream mapping projects included in 'B. Continuous improvement'	
23)	**Initiation of projects**	General and specific discussions about how/why/with whom a project gets started Sometimes discussion of routine vs. project-based work	19. Practices and Approaches
24)	**Criteria & constraints** (Design constraints/trade-offs/compromises/criteria/ objectives)	Indicators/metrics Performance concerns (explicit discussion on efficiency, productivity, quality, performance objectives/goals) What are the relevant factors? What do they consider? Goals and Objectives	25. Priorities 26. Role of Data
25)	**Priorities**	What design factors are prioritized when choosing projects? How is work prioritized? Includes some references to ergonomics: how health and safety and human factors projects are compared to	22. Criteria and constraints

		others Usually is a description of the process of prioritization rather than listing of the actual priorities	
26)	**Role of data** (discussions about the importance of data, what kind of info counts) **a. Quantitative data** **b. Qualitative data** **c. Other data-related comments**	Why they collect data and how they use it Limitations of data Challenges obtaining data A, B, C structure not that useful in this case, better to look at as a whole	24. Criteria and Constraints
27)	Participative/consultative approach [**Participation& Consultation**](active participation by stakeholders, specific mentions, examples)	How and why users are brought into the design process (selling an idea, creating buy-in, gathering information, etc.) Not always consistently applied, grew to include general descriptions of user input towards end of coding	33. Managing Change 34. Feedback and Follow-up
28)	Health and safety/ Ergonomics concerns **[Ergonomics (Personal)]** a. Impact of ergonomics on workers **[Impact on users]** (productivity, motivation, loyalty, job satisfaction, etc.) b. Impact of ergonomics on organization in general **[Impact on org. in general]** c. Perception of IE's impact on work environment **[Impact**	Ideas, conceptualizations, opinions, values, philosophies, etc. (What they THINK and BELIEVE, not necessarily what they do or what goes on in their company) Personal measures to address HF that are not expected by organization Conceptualization tends to act as a catch-all for this code, divisions between A, B, C not that effective E. Other tends to include mentions of their training/experience related to HF and ergonomics Sometimes hints at priorities/criteria for design	24. Criteria and Constraints

	on work environment] d. **Conceptualization of ergo**nomics (attitudes and perceptions) **e. Other**		
29)	**Other issues** (e.g. ethical, legislative, systemic, semantic i.e. ‘hf’ vs ‘ergonomics’)	Pretty much empty, almost everything is put in culture and context instead	31. Culture and Context
30)	**Barriers & Assists** **a. To Ergonomics** b. **To General Practice**	Barriers and assists to professional practice of engineers. Catch-all for barriers and assists mentioned at any point in the disucssion. Opportunities for entry of Ergo to workplace. Communication and information flow/information access are common subthemes Sometimes applied inconsistently: sometimes entire interviews read like a description of barriers/assists so there is some judgment applied when deciding what to actually include	37. HF Integration 38. Future-oriented IE
31)	**Culture and context factors** (impact of societal issues, business practice, economy)	‘society’ level of influence Includes organizational issues Somewhat broad, catches a lot of ideas	29. Other Issues
32)	**Communication** (discussions about communications related to the process of IEs doing their job) a. **Argumentation** (building a case for a project, i.e. convincing management, supporting, persuading, including cost-benefit	Explicit discussions about the importance of communication ‘B’ and ‘C’ were not large codes in the ergonomist interviews Goal-hooking as it relates to convincing and communicating about projects	19. Practices and Approaches 33. Managing Change

	arguments) b. **Information flow**/path of communications through organization **c. Other**		
33)	**Managing change** (discussions about success rate, barriers, assists, reactions and processes/activities related to implementation)	Obstacles to change (particularly implementation) faced in the organization and how they maneuver around these obstacles Goal-hooking as a strategy for managing change (also see arugmentation) Political Reflective Navigation Most implementation issues here Includes discussion of ‘convincing’ and consensus building: how do you get people to follow your plans, how do you elicit the behaviour you want?	19. Practices and Approaches 32 A. Communication: Argumentation
34)	**Feedback&follow-up** (how feedback is received, usefulness of feedback, importance of feedback, use of feedback, frequency, etc.)	Monitoring implemented systems Feedback from people or through measures/data	27. Participative/ Consultative 35. Endpoint/Signoff
35)	**Endpoint & signoff procedures** (how you know when the project is done, how you judge success of a project, when you move on, any administration related to project hand-off)	Touches on issues of continuous improvement and feedback Criteria tends to be somewhat ‘fuzzy’ – ex. User satisfaction, seems good enough, run out of time, etc.	34. Feedback/Follow-up
36)	Existing Ergonomics or Health and Safety activities **[Ergonomics (Existing in org.)]** a. **Stakeholders** involved **b. Policies & programs**	What is actually being done at their organization about ergonomics Corporate level: company-level/processes, mandatory measures or supports in place for HF work *Institutionalized measures* Can include personal actions or knowledge of actions	

	c. Experts (consultants, ergonomists) **d. Measures, indicators, risk factors** **e. Other**	within the company Unintended HF benefits? → scenarios where coder notes HF benefits not cited by interviewee ‘E. Other ‘includes training (usually) Be careful of subcategories: there is not always a clear distinction of what goes where	
37)	Discussion related to **HF integration** (present and future).	Integration with design process, communication, relationship building, risk factors, dose, education, etc. Examples: - OHS sidecar - Desired point of entry into the process - Barriers such as awareness, the lag in ergonomic effects (not always immediately apparent) Usually future oriented discussions, but not always	19 B. Practices and Approaches: Ergonomics 30 A. Barriers and Assists: to Ergonomics 36 B. Ergonomics (existing): Policies and Programs
38)	Future oriented discussion related to industrial engineering **[Future-oriented IE]** **a. communication** **b. integration with organization** **c. Other**	Like code 33 only for IE issues rather than ergonomics issues FUTURE! Corresponds to last question in the interview Not that big of a code, role of IE tends to catch some of these issues	21. Role of IE 30 B. Barriers and Assists: to General Practice
	ENGINEERS	**DESCRIPTION/NOTES**	**RELATED CODES**

C	**DATA GATHERING: Tool discussions (descriptions of specific tool usage)**		
39)	**AutoCAD&Solidworks**		
40)	**Time Study**		41. MOST/MTM 52. Equipment
41)	**MOST/MTM**		40. Time Study
42)	**Lean**		
43)	**Process map or chart**	Value-stream mapping (include BPMN) *Sometimes* includes other types of charts/ diagrams (spaghetti diagram)	53. Other tools and Approaches
44)	**Six-sigma (quality tools)**		
45)	**Simulation**		
46)	**FMEA**	Only in one or two interviews	
47)	**Camera (video or still)**		
48)	Books, Articles, Standards and Regulations (Grandjean, ISOxxxx, CSAxxxx, Anthropometric texts like Pheasant) **[Reference Material]**	Standards and regulations related to ergonomics are usually included under ergonomics tools	50. Ergonomics tools
49)	**Qualitative Methods** (e.g. observation, interviews, focus groups, informal discussions related to information gathering)		

50)	**Ergonomics tools** (e.g. in house checklists, standards, limits)		
51)	**Software – Other** (e.g. Excel, statistics packages, ERP software)	Microsoft Office mostly	
52)	**Equipment** (e.g. force gauges, stop watches, measuring tape)	Stop watch comments usually included under ‘Time study’ (the most popular context of use)	40. Time Study
53)	**Other tools and approaches** to gathering and analysing data (e.g. cost-benefit tools)	Work instructions/work standardization/standard operating procedures, communication tools	43. Process map or chart
54)	**Tool wish list**	What tools do they wish were available for their work?	55. Tool Uptake
55)	**Tool uptake** (usage decisions)	How are tools selected? If a new tool is desired, how is it brought into the organization?	54. Tool wish list

Appendix F: Tool use

	Most frequently used tools as reported on email survey					
	1	**2**	**3**	**4**	**5**	**Other**
ENG-01	video/stop watch for time motion study; 5S (elimination of all 7 wastes)	CAD	Six Sigma/ LEAN manufacturing tools - line balancing/ Kanban/ Takt time analysis/ spaghetti, etc.	material flow - gravity racks, use of tugger, roller lanes, JIT delivery	Simulation (ARENA)	FEMA, benchmarking, non-dynamic simulation (i.e. mockup and test, physical simulation)
ENG-02	MOST (Pre-determine time study). Use Stop watch analysis to verify my MOST analysis and to determine cycle time.	Six Sigma Methodology **DAMIC** - Define-Measure - Analyze - Improve - Control	Lean Principles, minimizing all the waste (MUDA) in the system and implementing the 5s principles.	Standardized procedures and work introductions	CAD	Process FMEA
ENG-03	Software (CAD, Solidworks)	Time Study	Stopwatch/ measuring tape	interviews	HD camcorder/ camera	Health and safety checklists from the ministry of labour
ENG-04	AutoCAD	process charts	Value-stream mapping	Microstation	NIOSH	MTM-1, SWTS, MOST, spaghetti diagram, measuring tape, stopwatch, mentioned checklist for health and safety/ergonomics requirements provided by corporate headquarters
ENG-05	ISO/TS16949	FMEA	MSA	APQP	AutoCad & Solidworks	MS Office (Visio, Access, Excel), PFD, Standard Work Chart, Man-Skill Chart, QSB Charts, Ergonomics (Konz & Johnson, Work Design), Health & Safety (machine safety Z4232-04, Z142-02 standards and OHSA), Lean Manufacturing Techniques (S. Bell, Lean Enterprise Systems; J.K. Kilker, The Toyota Way Fieldwork), Physical tools (measuring tape, stopwatch, camera), Neufert Architect Data, hourly employees' union agreement
ENG-06	Microsoft Office (Excel and Access)	CAD	Dynalab Software	Oracle/ JDEdwards (ERP)	Time study	OR modelling (Lindo software once), ergonomic guidelines, APQR (program management purposes), measuring tape, stop watch, soldering iron, basic maintenance tools, spaghetti diagrams, graphs and reports (histogram, pie graphs, some forecasting reports, efficiency/utilization/productivity graphs)
ENG-07	PlanOp - Network planning and analysis	MOST	PDA (UMT software)	stopwatch	7 steps to continuous improvement process	Arena Simulation, AutoCAD, MHE and facility design

ENG-08	simulation software	excel designed tools for time study or scheduling	Visio/CAD for layouts	time study	process study	physical tools (stopwatch, measuring tape, counters, anything needed to measure distance, quality, quantity, time, units of time), VSM, Process charts, diagrams as a visualization tool, emphasizes importance of past experience and training
ENG-09	MS Office (Excel, Visio, Word)	Minitab	Business process modelling notation	Joint Application Design (JAD)	Organization charting	competency modelling (defining jobs, what skills required), variance matrix (from socio-technical design, used for quality control), stopwatch, tape measure, six sigma
ENG-10	MS Outlook (email and scheduling)	MS Communicator (instant messaging)	MS Sharepoint (web design)	Zoomerang (survey creation)	MS Visio and BPMN (business process diagrams)	MS Word, MS Excel
ENG-11	AutoCAD	Solidworks	MS Project	Measuring Tape	Financial Package - corporate	Internal health and safety tool kit, legal guidelines for the country they're working in, Hydrometer, simulation, decision matrix
ENG-12	Stopwatch/ Measuring tape	Camera/ Camcorder	Micro-Station	MS Office	SPSS	Safework, Time and Motion study, Facilities Planning, Ergonomics/Safety Analysis, Economics Engineering Analysis, Lean Manufacturing, Process Management, Six-Sigma, Change Management, etc.
ENG-13	PDA (Physical Demands Analysis)	JSA - Risk Analysis (Job Safety Analysis)	Value Stream Mapping (VA, NVA, Necessary)	CAD	VISIO - Work Flows, Information Flows, Standard Operating Procedures	Methods Engineering - MOST / Work Sampling, Stop Watch Time Studies, Cycle Time Analysis. Work Load / Flow Balancing, Buffer & Balance, Bottle neck analysis, Capacity constraints, Throughput Analysis
ENG-14	AutoCAD	measuring tape	Standard Data (time study)	Ergo Evaluation Work Sheets	Force Gauge	MS Excel, MS Powerpoint, camera, simulation (simcat), NIOSH, Energy Expenditure, Stop Watch, PM&C (Production Monitoring and Control, live data from assembly line)
ENG-15	time study	stop watch	spaghetti diagram	process mapping	Gantt charts	simulations (simul8), Statistical Analysis (Minitab), excel, would like business intelligence software to be implemented
ENG-16	Process analysis with flowcharts and work sampling	Time studies with a stopwatch	Information Systems evaluation via a list of design heuristics	MS Excel	Observation	Interviews

ENG-17	Observation/ Interaction with employees performing/ supervising the task	GM Standard Data (pre-determined time study charts)	production schedules	AutoCAD	Job Element Sheets / Standard Operation Sheets (detailed work instructions)	Process Flow Diagrams, Man/Machine Chart, Corporate Guidelines for reach/weight/repetition, Force Gauges/Tape Measure/Scales, Design Ergo. Worksheet (corporate Ergo Evaluation Checklist), Professional Consult (Plant Ergonomist, Safety Specialist, Other IEs), Layouts, Scrolling Diagrams (moving line work sequence illustrations), Delay studies / work sampling studies, Witness Simulation, Safety Survey / Workplace Organization Audit, Team Meetings, Pictures
ENG-18	AutoCAD LT	Customized video time study software tool (in development)	Measuring tape, stop watch	MOST pre determined time study (by Kjell Zandin)	Man-Machine analysis chart	FMEA, Statistical process control
ENG-19	AutoCAD	Microsoft Office (Excel, Word, Access, Powerpoint, Visio, Project)	Adobe	SAP	MOST	Line Balance software, Lean training materials: Waste Elimination; Team Building; Factory Simulations and Layout Improvements; Setup reduction; Problem Solving (Storyboarding, 5-Whys; Root Cause Analysis, Pareto analysis); Value Stream Mapping, Setup Reduction; TPM-OEE; Quality Awareness-Poke Yokes; 5S; Kaizen Blitzes, Cellular Design; Process Mapping(Business process reengineering), Tools: Spaghetti diagram, Layouts, Signs: (Corplast, Whiteboards), Other: Stopwatch, Tape Measure, Floor tape, Stopwatch time study charts, Process Capacity Charts 6. Reference Materials: Lean Manufacturing publications esp. The Toyota Way; Lean Enterprise Institute publications (Learning to See, CreatingContinuous Flow, Making Materials Flow etc., Mixed Model Processing); Workstation design catalogs; CREFORM catalogs