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Process Mapping as a Tool for Integrating Human Factors into Work System Design

Aileen Joyce Lim
Ryerson University

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by

Aileen Joyce Lim
BEng Industrial Engineering, Ryerson University
Toronto, Ontario, Canada, 2008

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Abstract

This thesis explores the utility of a production system development process (PSDP) map as a tool for identifying process improvement opportunities with a focus of integrating human factors (HF) into work system design. In this university-industry action research collaboration with a Canada-based electronics manufacturer, 91 meeting events involving 31 personnel took place. The creation and application of the PSDP map led to process improvement ideas with an implementation plan over 14 sub-projects, as well as evidence of organizational change towards applications of proactive HF in design. Results showed that critical issues of PSDP mapping initiatives include data collection methods, scoping, level of detail, style, content and implementation. It was concluded that a process mapping approach to work system design is an effective method for identifying process improvement opportunities with consideration for human capabilities, though further research is required for implementing and sustaining process improvement changes.

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Table of Contents

List of Tables

List of Figures

List of Appendices

Chapter 1 - Introduction

The project 'Ergonomics in Production System Development' is a three part study by the Human Factors Engineering Lab at Ryerson University. This action research study entails working with a Canada-based electronics manufacturing company with global operations to integrate human factors (HF) considerations into their production system development process (PSDP), with the goal of achieving better production performance while reducing risks to operator health. This thesis describes the first part of a larger project, where the company's PSDP was examined through the creation and application of a PSDP map and engagement with stakeholders. Challenges in, and opportunities for, integrating HF were examined along with participant responses throughout the study's activities in order to develop and evaluate the applied design process mapping approach. Not included in this thesis, the second part to the larger project will entail the development and embedding of key HF indicators into the PSDP with a gained understanding of the PSDP from part one, while the third project element will follow the implementation of process changes.

1.1 Need to integrate HF into design

According to the International Association of Ergonomics (2010):

> "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."

Considering human capabilities in work system design has potential to improve both injury risk and business performance. According to socio-technical design theory, work systems are formed by the interaction of social and technical sub-systems within an organization (Cherns, 1987; Pasmore et al., 1982; Trist, 1981). These social and technical sub-systems must be effectively integrated for optimal work design in order to reap various benefits including injury prevention and improvements in business performance (Carayon, 2006).

1.1.1 Injury prevention and business benefits

75% of manufacturing employees or over 1.3 million individuals in Canada work in production (Industry Canada, 2010) and are at risk within an industry which has the highest number of work-related injuries per year (Human Resources and Skills Development Canada, 2010). In Ontario alone, occupational injuries, illnesses and fatalities affect thousands of workers, as well as their families, communities and workplaces each year, with an accumulated economic impact estimated at $15 billion annually (WSIB, 2008). It has been shown that direct and indirect costs of work-related ill health are comparable to those for all cancers combined (Leigh et al., 1997). As illustrated by this large magnitude of social and economic cost, there is an obligation to improve workplace health and safety and a need for proactive ergonomics in work system design (WSIB, 2008). Falck et al. (2010) define proactive ergonomics as analyzing and foreseeing ergonomic problems and quality risks based both on scientific research and practical experience. In addition to injury prevention benefits, the integration of HF in design has potential to yield business benefits. ‘Hidden’ indirect costs of work-related illness such as retraining and production delays have been shown to be greater than direct costs, which include not only occupational health and safety costs but performance declines as well (Oxenburgh et al., 2004).

Considering humans in work system design can prevent performance decline and actually help to improve performance (Dul & Neumann, 2009; Genaidy et al., 2009; Goggins et al., 2008; Oxenburgh et al., 2004).

Integrating HF at the stage of early system design enables increased flexibility (Miles & Swift, 1998) and thus greater opportunity for maximizing design potential in domains including productivity and quality (Gonzalez et al., 2003). The availability and understanding of more process details at the design stage reduce the likelihood of obtaining defective work from that process, thus improving quality outcomes (Anjard, 1996; Falck et al., 2010; Soliman, 1998). This shift from conventional 'end-of-pipe' exposure control to process design also reduces barriers to productivity and economic development (Quinn et al,. 1998). The improvement of product quality, as well as business development through early integration, supports competitive advantage, which is a major concern for businesses commonly challenged by increasing market pressures towards short product lifecycles (Riedel & Pawar, 1997). These short lifecycles require rapid design and production, and leave little or no room for time to retrofit the work system. Falck et al. (2010) emphasize the value of early considerations in design and production planning phases:

> "It is extremely important to establish ergonomics requirements and to apply a holistic view at product level as early as possible because, in early design phases of new products and in the production planning phase, changes are less costly and easier to make than are late changes to the product, the work, or the workplace design. In addition, changes are increasingly difficult to make the closer it is to production start, and they become much more costly."

The consideration of production aspects early on is thus more cost effective from a business viewpoint, as well as with associated costs due to injury which has roots in work system design

(Neumann, 2002, 2006). Furthermore, injury prevention through early design considerations has potential to reduce risk of negative system outcomes.

1.1.2 Need for approach

It is often argued from an economic and ergonomic point of view that ergonomic considerations should be integrated into planning processes, but it is seldom the case in practice (Jensen, 2002). In order for this to be effectively implemented, such an effort would need social adoption into mainstream consciousness "to embed the prevention mindset in social norms, values and beliefs" (WSIB, 2010). This requires organizational-level change involving the linkage and integration of processes across an organization (Armistead & Machin, 1997; DeToro & McCabe, 1997). Holden et al. (2008) note that, although there is a large body of macroergonomic research available (Hendrick & Kleiner, 2002), additional guidance is needed for field research. Furthermore, within the wide range of ergonomic tools available, there is a gap in terms of system-level tools for identifying opportunities to integrate HF into early design decisions (Neumann, 2007; Neumann et al., 2007). A logical first step to the integration of HF into planning processes would be to develop an understanding of the design process.

1.2 Business process mapping

Business process mapping is a common industry practice used to illustrate the current state processes within companies, in order to identify process gaps and future state goals (Soliman, 1998). As the central approach used in this thesis, process mapping was applied as a tool for analyzing early processes in production system design. This methodology enabled the researchers to analyze the design process as currently practiced and establish a 'map' for cross-functional discussion on process improvement efforts.

1.2.1 Process mapping background

Coined by Hammer and Champy, 'business process reengineering' (BPR) is defined as *"the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures such as cost, quality, service, and speed"* (Siha & Saad, 2008). Many organizations have turned to BPR to improve their competitive position through simplification, elimination and redesign of business processes for increased efficiency and cost reduction; leading to an increase in the number of BPR projects undertaken (Soliman, 1998). As summarized by Al-Mashari & Zairi (2000), "a business process has structure, inputs, outputs, customers and owners, and is built up by integrating fragmented functions that contribute to its operations and internal and external flows". Key elements of the business process model are people (i.e. skills, attitude and culture required), the information technology (IT) system (i.e. software and hardware to support information flow), technology (i.e. facilities and equipment required), process (i.e. activities required to achieve critical success factors), infrastructure (i.e. layout, material flow, etc.), and organization (i.e. the structure required to operate the process (Wu et al., 2010).

The most important and fundamental element of BPR is business process mapping (Soliman, 1998). Process mapping is a technique used to detail business processes through a graphical description of business activities and flows by focusing on the important elements that influence their actual behavior. As described by Siha and Saad (2008), *"Process mapping offers a 'visual* *aid' to process improvement and provides a means for analyzing the process…It is a framework that shows relationships between the activities, people, data and objectives"*. According to Soliman (1998), process mapping is usually performed over 3 steps:

1. Identifying products and services and their related processes, including starting and finishing points of processes.
2. Data gathering and preparation.
3. Transforming the data into a visual representation in order to identify bottlenecks, wasted activities, delays and duplication of efforts.

1.2.2 Process mapping applications

Process mapping has been applied in a wide range of industries including manufacturing (e.g. Paper et al., 2001), construction services (e.g. Macmillan et al., 2002), and healthcare (e.g. Potter et al., 2004). The business process modelling view yields well documented value, including providing a holistic perspective on how the business operates, providing a means of documenting processes, providing a vehicle for development and communication (Barber et al., 2003), aiding in eliminating non-value added activities and reducing process complexity (Soliman, 1998), aiding in knowledge capitalization (Renaud et al., 2004), and aiding in managing company artifacts (Kang et al., 2003).

Though process mapping projects have potential for many benefits, there are challenges that may be faced in implementation. Wu et al. (2000) identify 3 key challenges in analyzing business processes: 1) the structuring of the analysis or learning process to ensure total coverage but avoiding duplication, 2) the comprehension of the complex system of processes and the complexity of the processes themselves, and 3) the identification of the underlying qualities of a process or what makes it work. An additional major challenge is in the level of detail of mapping activities. A common terminology used to differentiate levels of detail is “macro-maps” referring to an overview level, while “micro-maps” are at a very detailed level. Anjard (1996) suggests that process maps be developed from the top-down approach analogous to ‘peeling the onion’, starting with the macro-level or highest level of a process to determine scope, then ‘peeling’ down to the next level to assimilate the complexity of details into a comprehensive level. The last step to this approach entails breaking the comprehensive level down into micro-level with the finest details of the system. However, Soliman (1998) argues that the research for increased detail comes at the higher cost of increased effort and execution, and suggests a goal of obtaining an optimum level of process mapping. On the comprehension of the business processes (Wu et al., 2000), he comments that a visual representation of the process tends to isolate crucial information and, accordingly, fewer levels of the map could result in greater abstraction and thus less process detail (Soliman, 1998).

Development in business process mapping methodologies is needed for guidance on implementation. Many tools exist and are used for representing and analyzing business processes, but little information is available on how these tools are used in practice (Fulscher & Powell, 1999). In particular, there exists a key gap in knowledge on business process mapping for HF applications. Based on the author’s literature review of scientific and business databases, process mapping has not been used to assess design processes for HF integration. Jarebrant et al. (2009) developed an ergonomic complement to the value stream mapping tool within the lean philosophy for considering job content in hospitals, though this tool is activity-level focused and not at the design process level which implies retrofitting rather than proactive prevention.

Further research is also required on incorporating process mapping and analysis in wider participative organizational development strategies. Buchanan (1998) argues that “cross-functional analysis of workflows in an organization, and novel ways visually of representing activity chains can be used to legitimatize and to trigger a creative dialogue concerning ways to redesign work processes”. With responsibility for human factors distributed across organizations since design decisions at all levels affect operator and system outcomes (Neumann, 2006), an organizational development approach would be ideal for HF analysis and process integration.

1.2.3 Adapting a mapping-based study approach

Neumann et al.’s work system design model (2009) considers a chain of interrelated design aspects which users interact with, namely: 1) organizational strategy, 2) production strategy, 3) system design, and 4) the production system (see Figure 1). The model illustrates the consequences of a series of decisions which can lead to risk for system users and affects on system outputs such as efficiency and quality. Designers at each system level influence HF outcomes through their design decisions at each stage, which further define the design and thus constrain later decisions. The complexity of decisions required in production system design requires a thorough understanding of company decision-making processes in order to change PSDP design outcomes.

Business process mapping provides a logical starting point for understanding the PSDP and HF relevance in all aspects of the production system. This thesis focuses on the work system design process with the end product being an implemented production system design capable of supporting mass production of electronics. Process mapping can potentially help to identify HF opportunities in production system design. It can serve as a means for communication between cross-functional staff, allowing stakeholders to develop a common understanding of the PSDP to work together while sharing perspectives. Neumann (2009) expresses that design process mapping could be potentially useful in supporting organizational-level change efforts of integrating ergonomics, though this was not detailed or well explored. There appears to be no other existing literature on the application of process mapping to design of processes, and furthermore only theoretical discussion of HF input into processes, though not as an analytic tool (Jensen, 2002). This thesis will contribute to this knowledge gap and those described in section 1.2.2 by addressing the use of process mapping as a tool for organizational development strategy for HF integration into the design of processes, and providing guidance on implementation.

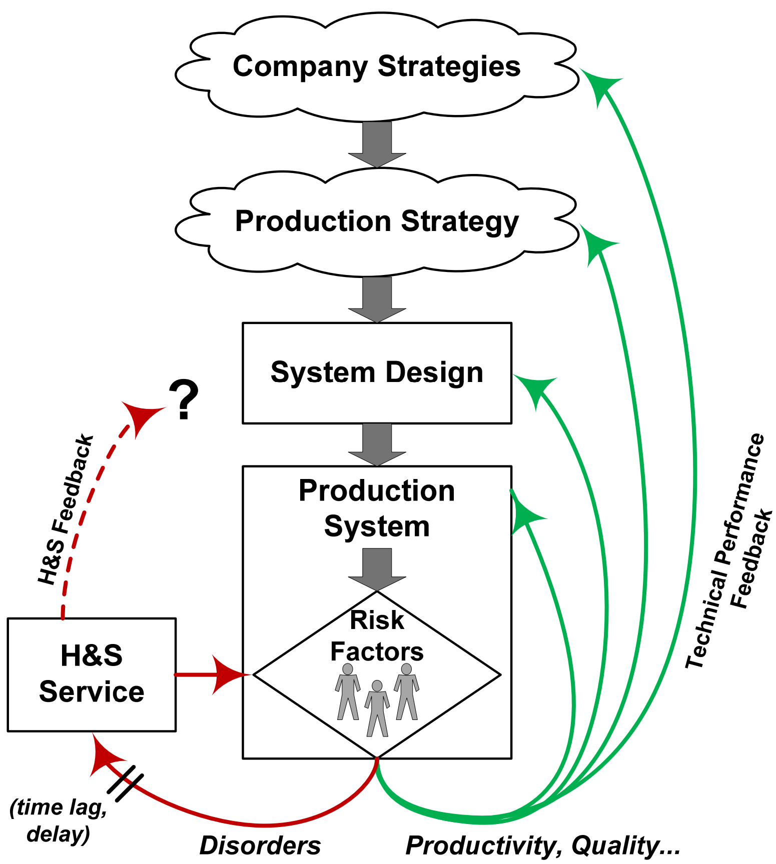

Figure 1: Work system design model, adapted from Neumann et al. (2009)

1.3 Objectives

The objective of this thesis is to explore the application of process mapping as a tool for design process change. Process mapping is typically applied to *existing* work systems to improve process flows, thus limiting design opportunities. In this mapping study, the process of *designing* work systems was chosen to include optimal considerations for performance, as well as operator sustainability during process development. The application explored was testing the utility of this approach in integrating HF considerations into the PSDP of a Canadian electronics manufacturing company, and it was intended to help the company and research team identify opportunities for improvement to the PSDP. At the beginning of the study, company personnel noted that a documented, comprehensive description of the current process did not exist.

This study will contribute to an understanding of how HF can be effectively integrated into real-world product development processes, an area lacking research, through the identification of barriers and assists to this approach. Drawing upon the insight gained from Neumann and Winkel (2006) that HF responsibility is distributed across an organization and requires organizational-level change, the project will address the organizational design aspect and as a result product and process design will be indirectly studied.

The specific objectives of this thesis are to:

1. Explore an approach to applying process mapping as a tool for improving production system design processes with a focus on HF integration.
2. Test the utility of the PSDP map tool for stimulating organizational change towards proactive HF through the generation of process improvement ideas.

3. Identify aids and barriers to this approach from PSDP map applications with industry stakeholders.

4. Suggest recommendations for future applications of mapping design processes based on lessons learned from this study.

Chapter 2 - Methodology

The methodology used in this research is described within the context of a larger research effort (section 2.1) and the study participants are described (section 2.2). A mixed methods approach was applied within the jointly planned study activities (sections 2.3-2.4) listed in Table 1. Key events that occurred during these project phases are summarized in the 'key events table' (Table 4), which serves as a reference for the event numbers noted throughout this thesis.

Table 1: Summary of study activities and data collection methods

Study activities	Methods for data collection
• Map creation - Initial interviews - Process map construction - Process map verification • Map application trials - Map application with ergonomist - Workshops • Process evaluation	• Field notes • Event tracking • Interviews • Feedback evaluation forms

2.1 Study design

The overarching study is a longitudinal case study with the objective of studying the factors influencing the success of an organizational change effort to integrate human factors (HF) into the participating company's production system development process (PSDP) (Lim et al., 2009). This thesis describes the first initiative of this larger action research project which assessed the company's current PSDP through process mapping applications. This initiative was chosen collaboratively with company personnel to create a common understanding as a basis for decisions on how best to develop the PSDP, thus providing a starting point for organizational development.

This study took an explorative, qualitative and mixed-methods approach with a basis in program evaluation science, namely utilization-focused evaluation (Patton, 1997), which allowed for flexibility in decision outcomes. A qualitative and ethnographic approach was applied to provide insight into stakeholder perspectives and responses to the study activities from within the company culture (Ball & Omerod, 2000). Activities took place in a collaborative 'action research' mode in which researchers collaborate in the change effort (Reason & Bradbury, 2001; Ekman Phillips & Huzzard, 2007), with continuous observation and documentation throughout all stages supported by audio recordings and field notes. This approach serves both the immediate needs of the company for an improved PSDP as well as the longer-term needs of research to develop better ways to help companies improve their PSDPs.

2.2 Study participants

The study began with an environment, health and safety (EH&S) manager as the project lead once the senior director of engineering (SDE) had approved the project as the company sponsor. The EH&S manager acted as liaison between the university researchers and the company, and arranged the assignment of an ergonomist and an industrial engineer (IE) as project coordinators (PCs) in order to maintain both the HF and engineering viewpoints. These company personnel formed the initial project team within the company and subsequently identified additional stakeholders to engage as the study developed.

2.3 Data collection methods

Throughout all phases and activities, this study applied four separate data collection methods: 1) field notes, 2) event tracking, 3) interviews and 4) feedback evaluation forms. Haims and Carayon (1998) note that the use of several methods creates multiple sources of evidence “for testing the proposed model and for developing preliminary design principles”, and add that combining quantitative and qualitative research techniques both enhances the validity of study findings and strengthens the implementation process and outcome.

2.3.1 Field notes

Field notes were made by the author throughout the duration of the project. Each note was initiated by collaboration events such as site visits or phone meetings with company personnel. With key event information recorded such as date and key participants, notes were taken including key discussion points, speakers, and start times of key discussion points if the event was being digitally recorded. Following each event, audio recordings were reviewed and key events were transcribed to identify key quotes and verify field notes. Each note included author annotations and a reflection on observations, project concerns, accomplishments and next steps. Emergent themes within the notes were analyzed using the general inductive approach for analyzing qualitative evaluation data (Patton, 2002; Thomas, 2006) and key codes were identified (described in section 3.1.3.1). Lastly, each project note included a narrative of key events that followed the current event but preceded the next to close gaps in study narration.

2.3.2 Event tracking

All project events were tracked in a Microsoft Excel workbook which served as a summary of contact information and data management. The key contact information recorded were the meeting number, date, attendees (university researcher and company attendees), type of contact (phone meeting or on-site; if on-site then meeting, interview session, floor tour, or workshop), contact time, brief description and key topics. This was also used as a data management tool due to the large amount of project documents such as field notes, audio and transcript files, documents created by the university researchers (e.g. project updates, interview outlines, etc.), and company documents provided (e.g. process forms, diagrams, etc.).

2.3.3 Interviews

The author conducted 2 sets of semi-structured open-ended interviews with both individuals and groups; 1) initial interviews at the start of the study to collect PSDP data for mapping (key event 2) and 2) methodological evaluation interviews at the end (key event 13). The company-approved study information sheets and interview topic outlines (Table 2 and Table 3) were provided to the participants before each event. Both PCs were present at each event and actively participated in the discussions. Full transcripts and notes were sent to participants for content verification. The participants were approached with follow-up questions as the project and new understandings developed, providing an iterative element to the investigation of current practices in the company.

2.3.4 Feedback evaluation forms

The effectiveness of the map application trial in Workshop 1 (key event 10) was assessed through questionnaires. Participant perceptions on both the workshop experience and the application of the map were captured through qualitative questions. These were distributed at the end of the workshop and collected after completion. The forms were collected and processed by the author, and the results were shared with the company through a qualitative summary sheet.

2.4 Study Activities

This study's activities consisted of three distinct stages: 1) map creation, 2) map application trials, and 3) process evaluation. Throughout each of these stages, the project team discussed next steps in ongoing project planning meetings. The activities within these stages and methods used are described.

2.4.1 Map creation

Data collected from stakeholder interviews was the basis for creating the process map. Once verified with key stakeholders, the interview data was re-analyzed.

2.4.1.1 Initial interviews

The purpose of the 1-hour semi-structured interviews (key event 2) was to collect information about current processes from key stakeholders who together covered the entire PSDP. The PCs selected the initial participants who were identified as key resources for process information and scheduled the interviews. A general outline was followed for the discussions (Table 2), with additional tailored questions by role. Following the first set of interviews, a “snowball approach” was applied where later participants were selected based on study development and prior participants’ recommendations on where information was missing or needed (Patton, 1997). Since the PCs and project lead expressed that the interviews had covered the scope intended, the author ceased initial interviews and began map creation. During this process, relevant company documents were reviewed when available as complementary information.

Table 2: Initial interview outline used for process map data collection

Category	Specific interview topics
1. Introduction	• Overview of project and research team members. • Mention protection of privacy / confidentiality. • Permission to record?
2. Organizational structure	• How do you fit into the organization? • What are your responsibilities?
3. Role and processes	• Typical production system design processes including timelines, departments involved, and general work flow? • Tools (checklists, database, reference documents, etc.) used? • Feedback between departments? • HF and/or performance indicators? Past assessments?
4. General feedback	• Challenges to integrating HF considerations? • Recommendations for improvements?
5. Wrap-up	• Any tips on how to proceed with study? • Permission to follow up with questions after reviewing notes?

2.4.1.2 Process map construction

Using the initial interview transcripts and project notes as references, each of the processes described in the stakeholder interviews were broken down into sequential steps and illustrated as process maps similar to business process re-engineering diagrams using Microsoft Visio software. The author then manually arranged (or ‘pieced together’) the illustrations to her understanding of overall flow to form the larger PSDP, and presented the data to the PCs in a 1.5

hour session to verify each process map and discuss the relationships between the process map to best represent the company's current PSDP (key event 3). The author used the feedback to revise the sub-process maps and then moved each into corresponding 'swimlane' divisions of product phases within one larger document. This notation was adapted from the cross-functional process map (or flowchart) style, where process steps are placed within bands corresponding to the functional units responsible (Tillmans & Lin, n.d.) Connections between the sub-processes were added and final revisions were made, leading to the creation of the first draft of the 'complete' PSDP. This was reviewed by the PCs prior to use in process map verification meetings.

2.4.1.3 Process map verification

Verification meetings took place with the PCs and 5 key stakeholders in three semi-structured 2-hour long discussions (key event 5). The author led the sessions and sequentially ran through each section of the map while facilitating iterations of process explanation, content verification, and discussion. Clarifications were made and corrections noted, opportunities for improvement were revisited, and the participants discussed their perceived usefulness of the effort. Transcripts were verified by the participants and the process map was revised with the discussions and feedback. Since the participants expressed completion and validity of the PSDP map, this revised version was used as the final document for map applications within this study.

2.4.1.4 Interview data analysis

Comments on process and organizational limitations as well as ideas for system improvement opportunities emerged in both the initial interviews and the process map verification meetings.

The author reviewed these transcripts and key quotes describing challenges and opportunities were identified and compiled within an Excel spreadsheet with relevant context information (i.e. speaker, role, and date). Once an understanding of the emergent themes was gained, the author used the general inductive approach (Thomas, 2006) and assigned a code to each of the points. Results were presented to the research team and select company stakeholders in a planning meeting. This list was later re-clustered into a document summarizing the participant recommendations for management review (Appendix A).

2.4.2 Map application trials

Once the map was created and verified, map application activities were initiated. The main application events were 1) a map application session with the ergonomist, and 2) workshops.

2.4.2.1 Review of critical HF points with ergonomist

A meeting was held with the ergonomist to use the map as a tool for identifying key HF decision points in the PSDP (key event 7). In this 2-hour session, the author sequentially went through the map in a similar fashion to the verification meetings and facilitated iterations of process explanation, discussion of related human factors elements, and lastly discussion of where in each process key human factors decisions were made. As these iterations took place, key points were noted directly on the map by the author.

2.4.2.2 Workshops

The PCs structured and led an all-day workshop with the theme of ‘workstation and line layout design’ (key event 10). Participants outside of the research team were selected by the company to represent various departments. The senior researchers explained the collaborative study and provided introductory educational pieces to provide participants with a basic understanding of human factors concepts. In preparing for this event, the IE took initiative to create a new PSDP map as a tool for participants to identify opportunities for embedding ergonomic considerations. The IE facilitated this as well as a workstation design checklist creation activity by first briefly running through the created process map, and then asking the participants to brainstorm ideas in two equally divided groups of participants and researchers. With the IE taking notes on chart paper, the groups then presented their ideas, which the PCs later compiled and categorized into a summary.

A second all-day workshop was held to develop the results from Workshop 1 into a high-level project plan (key event 12). The workshop was jointly planned by the researchers and company, with 4 additional participants to the research team selected to participate. The document created by the research coordinators which summarized the results from the first objective of Workshop 1 was used as the basis for formalizing sub-projects with scopes, timelines, and resources. Led by the IE, the group then jointly prioritized the projects by discussing each point to estimate a plot point with respect to effort and impact, and then created a rough Gantt chart style 3-year timeline based on the plot. The plot and timeline were created manually on a meeting room white board and photos were taken of the resulting diagrams by the project coordinators to capture the effort. Workshops 1 and 2 were digitally recorded and documented by two separate university researchers.

2.4.3 Process evaluation

Following the final workshop, the author conducted one-on-one open-ended semi-structured interviews ranging from 30-min to 1-hour duration (key event 13). 6 participants were selected by the author and a senior researcher based on level of involvement throughout the project. The specific criteria to be met were participation in an initial interview, verification meeting, and at least 2 of the 3 workshops. The participants were provided the general outline in advance (see Table 3).

Table 3: Process evaluation interview outline used at the end of the study

Category	Specific interview topics
1. Process mapping	*Please comment on the potential of the mapping method applied in terms of :* • Learning (understanding your role, the production system design process (PSDP), and HF in the PSDP?) • Utility (in the act of creating the map, as a workshop tool, as a training tool?)
2. Alternative ideas	*Please describe alternative:* • Ideas for applying the map(s)? • Forms of the map(s) you think could be useful to you or your department? • Methods you think could be useful for stimulating change in integrating HF into PSDP's?
3. Future steps at Company X	*Please describe:* • Your understanding of future steps for the map(s) at Company X • Your understanding of future steps to be taken at Company X as a result of the mapping activities • Ideas/recommendations for the project in general (Aids/barriers? Advice?)

Table 4: Table of key events by study phase. This is a summary of the 13 key study events referenced throughout this thesis including event dates, descriptions and participants.

TABLE OF KEY EVENTS BY STUDY PHASE			
Key event #	**Event**	**Description**	**Company participants**
Phase 1: Project initiation			
1	**Project initiation meetings** (Oct ‘08 – Jan ’09)	- Meetings to discuss project objectives, scope, timelines, funding, and legal agreements	- EH&S manager (project lead), senior director of engineering (SDE) (sponsor), legal representatives, and project coordinators (PCs)
Phase 2: Map creation			
2	**Initial interviews** (Feb – Jul ’09)	- 1-hr long semi-structured interviews with individual stakeholders for process map data collection	- 13 stakeholders involved in assembly design decisions, 1 packaging stakeholder, and PCs
3	**Review of process maps** (Sept ’09)	- Review of stakeholder process maps for content verification and direction on creating PSDP map	- PCs
4	**Operator focus group interview** (Oct ’09)	- 1.5-hour long discussion about operator perspectives on production system design	- 4 operator leads selected by production management and PCs
5	**Map verification meetings** (Oct – Nov ’09)	- 3 verification meetings held in small groups of key interview participants	- 2 manufacturing engineers, industrial engineer (IE), equipment commissioner, manufacturing manager, and PCs
Phase 3: Map application trials			
6	**Kick-off meeting** (Dec ’09 – Feb ’10)	- Meeting to align project expectations with new lead and plan workshops - Interview comments presented	- Manager of manufacturing engineering (ME) (new project lead), PCs, IE, and project manager (PM)
7	**Map review for critical HF points with ergonomist** (Feb ’10)	- Review of PSDP to identify critical HF points and determine process improvement ideas	- Ergonomist
8	**Meeting with director of engineering** (Feb ’10)	- Project explanation and update with new director of engineering	- Director of engineering and PCs
9	**Major project planning meeting** (Feb ’10)	- Presentation of map and interview/mapping results to team; workshop planning	- Project lead, IE, PM, and PCs
10	**Workshop 1: Workstation and line layout design** (Mar ’10)	- Full day workshop with 2 foci: Integration of HF into the PSDP and workstation design checklist creation	- 8 participants outside of the research team (e.g. production, quality, and packaging), PM, project lead, and PCs - SDE and director of ME visited
11	**Development of project proposal to upper mgt** (Mar – Apr ’10)	- Preparation of proposal to upper management to ensure alignment of expectations	- IE, PM, and PCs
12	**Workshop 2: High-level project planning** (Apr ’10)	- Development of HF integration ideas into sub-projects; prioritization and rough scheduling	- 4 participants outside of the research team (i.e. training, quality, production management, and packaging), lead and PCs
Phase 4: Process evaluation			
13	**Process evaluation interviews** (May ’10)	- 6 one-on-one interviews with key project participants to obtain feedback on the project	- 2 IE’s, equipment commissioner, manufacturing manager, project lead, and ergonomist

2.5 Data analysis and reporting

The author utilized the general inductive process (Thomas, 2006) in analyzing the data, where the collected data (i.e. transcripts, audio recordings, supporting documents and field notes) were reexamined for emergent themes, then compiled and analyzed for connections and patterns. Due to the exploratory nature of this study, the analysis did not restrict any themes as being out of scope.

In order to interpret the data, the researcher performed several cycles of analysis. During and following each site visit, the data was examined and themes were noted. The author's interpretation of the data was documented and then the data was reexamined for verification and refinement at major study phases. This practice involved iterations of deductive (theory informs data collection) and inductive (data informs theory development) analyses (Orton, 1997). Once a clear mental model of the results was developed, the researcher performed relevant literature searches to reference existing theory to strengthen and elaborate on central interpretations which had emerged. The results section of this thesis is organized by subheadings established during the data analysis process, in which supporting evidence is presented. The discussion section then incorporates additional insight gained from the literature to elaborate on the main results.

Chapter 3 - Results

The study ran over a period of 20 months from October 2008 to May 2010 and was divided into 4 phases: 1) project initiation, 2) map creation, 2) map application trials, and 4) process evaluation, illustrated in Figure 2. Over the course of the project, the author attended 91 meeting events with 31 company personnel totaling over 106 hours of contact time (see Table 5). These events consisted of planning meetings, activity events and production floor tours; 11 of which were conducted over the phone while the rest were planned over 36 site visits.

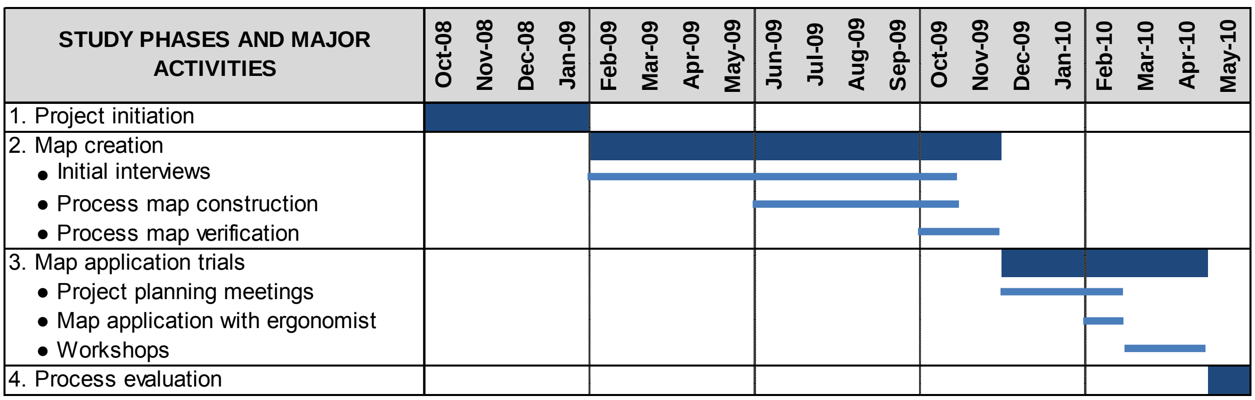

Figure 2: Project timeline. Since the research team decided on actions as the project developed, this illustrates the resulting time sequence and allocation for each of the phases and activities.

Table 5: Summary of number of project events and corresponding contact times with company.

STUDY PHASES AND ACTIVITIES	CONTACT DATA BY EVENT TYPE *No. = Number of Events; C.T. = Contact Time (hrs:mins)*								TOTALS BYSTUDY PHASE	
	Planning Meetings				Activity Events		Floor Tours			
	By Phone		On-Site							
	No.	C.T.	No.	C.T.	No.	C.T.	No.	C.T.	No.	C.T.
1. Project initiation	*1*	*0:45*	*10*	*13:45*			*1*	*1:00*	**12**	**15:30**
2. Map creation	*4*	*2:10*	*11*	*15:40*					**40**	**53:05**
• Initial interviews					*18*	*23:30*	*2*	*4:00*		
• Process map construction					*1*	*0:45*	*1*	*2:00*		
• Process map verification					*3*	*5:00*				
3. Map application trials	*6*	*3:45*	*23*	*13:00*			*1*	*0:45*	**33**	**32:30**
• Map application with ergonomist					*1*	*3:00*				
• Workshops					*2*	*12:00*				
4. Process evaluation					*6*	*5:00*			**6**	**5:00**
TOTALS BY EVENT TYPE	**11**	**6:40**	**44**	**42:25**	**31**	**49:15**	**5**	**7:45**	**91**	**106:05**

The various levels of results that emerged over this study are presented in 3 sections:

- *3.1 Mapping results* - describes the outcomes of the mapping activities.
- *3.2 Participant responses to mapping* – describes the various map-related participant opinions throughout the project.
- *3.3 Critical thinking in HF integration* – describes the observed development of the participants' understanding and approach to the HF integration problem.

3.1 Mapping results

This section focuses on the outcomes of the project phases and activities. Results of the map creation and application are presented in sections 3.1.1-3.1.2, and other results in section 3.1.3.

3.1.1 Map creation

The process map creation activities consisted of initial interviews, map construction (section 3.1.1.1) and map verification (section 3.1.1.2). To preserve company confidentiality, only example schematics will be presented in this thesis (Figures 3-5).

3.1.1.1 Initial interviews and process map construction

The EH&S manager expressed in early meetings that the map should be activity-based and constructed based on individual stakeholder interviews "to compare different perspectives" and reveal disconnects, and that group sessions could be held after a skeleton map was complete. The initial interviews took place over a period of 8 months and were primarily in the scope of assembly (see key event 2). The participants' descriptions of work processes and related tools, guidelines and metrics were detailed and insightful, and all stated that they weren't aware of any HF process indicators in the current system. From these interviews, 12 process maps were created in total. The first process map illustrated the production floor processes and was created based on interview data and floor tours. 11 additional process maps were created based on the stakeholder interview data as described in section 2.4.1:

1. Production floor processes
2. Product design
3. Prototyping planning
4. Prototyping
5. Workstation and line layout design
6. Equipment commissioning
7. Manufacturing manager tasks (high-level)
8. Manufacturing manager tasks (detailed)
9. Training
10. Production manager tasks
11. Reactive ergonomics process
12. Special projects

The map style consisted of boxes representing different steps, where shaded boxes were used to illustrate higher-level processes which involved sub-steps, since interview responses contained varying levels of detail. A diamond was used to illustrate a meeting where a major decision was addressed, such as the ‘line layout verification meeting’ where the production line layout design is finalized before implementation. Lastly, coloured circles were used to illustrate the creation of a document (e.g. concept design) or where an assessment is conducted (e.g. time studies); while hollow circles were used to represent where reference documents were applied (e.g. design guidelines). A sample stakeholder map is shown in Figure 3.

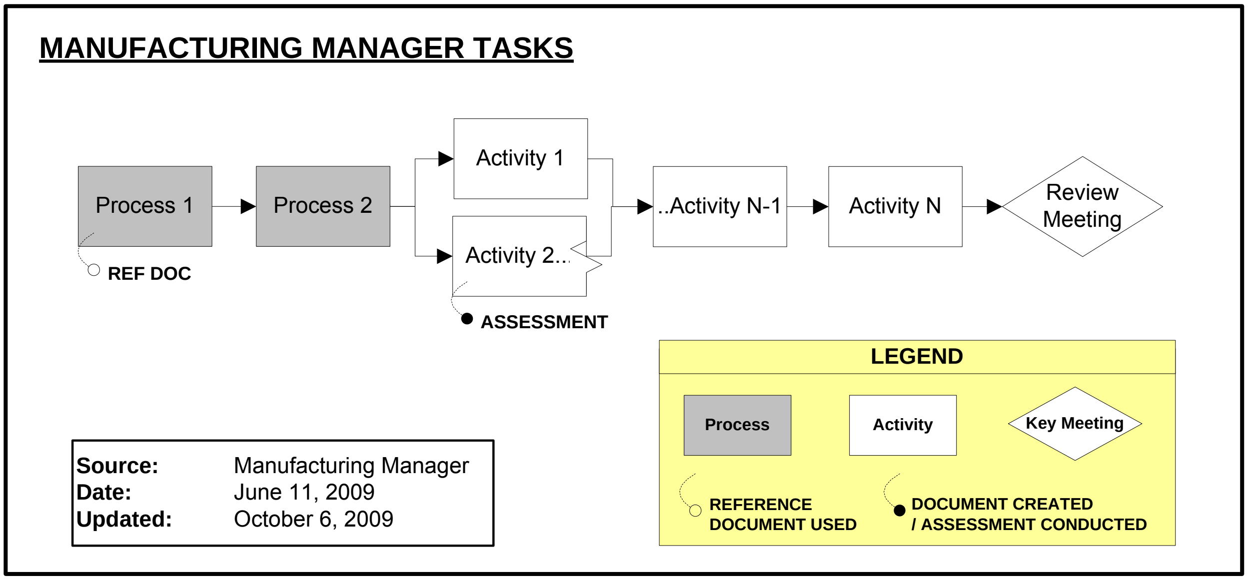

Figure 3: Sample stakeholder map of the manufacturing manager role for illustrative purposes.

The 12 process maps were presented to the Ryerson University research team in an order based on the author's understanding of process flow. The two maps which stood out as not part of the core process were for ergonomics (Map 11) and special projects (Map 12) since they were more reactive and only engaged when deemed required by other stakeholders as 'service functions'. These and the production management maps related to reporting processes were later removed from the PSDP map and instead illustrated in a simplified high-level version that only included major activities, shown in Figure 4. Discussions in this meeting highlighted the importance of mapping information flow, and the senior researchers suggested illustrating this as dotted lines connecting process boxes. This discussion led to the map review meeting (key event 3) with the PCs described in section 2.4.1, which aided in verifying the translation from interview content to process maps. The author identified 7 considerations for process mapping during the group review presented in Table 6, which helped to better understand the PSDP and complete the map.

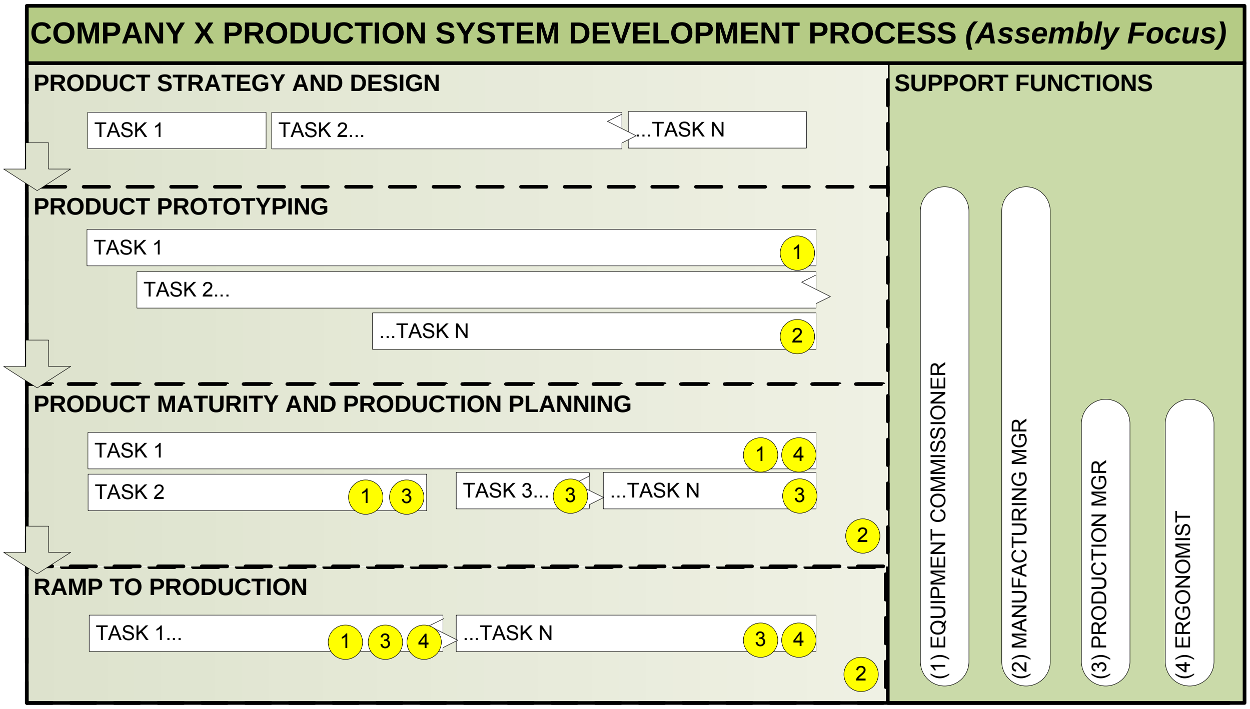

Figure 4: Sample high-level PSDP map with supporting functions for illustrative purposes. Horizontal placement indicates sequential order of tasks, while vertical alignment indicates parallel processes. Circled numbers represent where the 4 support functions on the right.

Table 6: Elements to consider when creating process maps, which emerged during the map review meeting with the PCs.

Mapping considerations	Meetings observations
1. Content errors	Content errors such as new stakeholders responsible for processes and new tool names were identified and corrections provided. This was especially useful since at this point, some of the information was outdated with changes to the production model.
2. Map overlap	The project coordinators were able to quickly point out where the same processes were covered on multiple maps, as participants sometimes referred to the same processes by different names. This was useful in combining the maps and getting different perspectives.
3. Sequence	The project coordinators provided feedback on the general sequence of the process maps for proper placement within the complete map.
4. Information flow / feedback	The project coordinators provided an understanding of information flow and feedback between departments to support map representation.
5. Ergonomist involvement	The ergonomist pointed out where and how s/he was involved in the process. This helped to illustrate where HF assessments were done and where they were absent.
6. Opportunities for improvement	A few ideas for improvement opportunities arose during process discussion, such as 3D simulation of the product to assess risk in manual assembly.
7. Missing Info	The coordinators compared the visual representations to their actual processes and pointed out information gaps. For example, they suggested additional stakeholder map reviews to better understand metrics and the role of manufacturing engineers.

In this group meeting, the PCs stated that they believed a fairly complete picture of the PSDP was attained. They added that no additional changes were required for the recent change in production model since only product volumes would change but processes would not. Three elements they thought should be added were information flow, timelines, and metrics. The author completed the PSDP map within the product phases described in the interviews and added dotted lines of information flow and metrics information attained from the interviews. Timelines were not illustrated because in the initial interviews, all of the participants stated that there were no standards in process timelines since durations significantly varied by product and demand within the company. Furthermore, the grey process boxes were eliminated because the overlapping information identified broke down the high-level activities into process steps.

3.1.1.2 Process map verification

On reviewing the first draft of the PSDP map, the PCs responded that it seemed accurate so this version was used for the verification meetings. Verification meetings were held in small groups for increased study efficiency (key event 5). The entire map was covered by the 5 context experts in 3 meetings held over 3 weeks. The participants noted that a major change in the company's production model required the product phases to be changed – a contrast to the feedback given by the PCs in the map review meeting. Three of the five participants' roles had changed due to this new production model implementation. Furthermore, the participants identified terminology changes, outdated tools/metrics, additional feedback links, and modifications needed to process sequences. The map was updated and sent to the PCs for review. Figure 5 shows a sample map with meetings and activities within tasks, as well as information flow between processes.

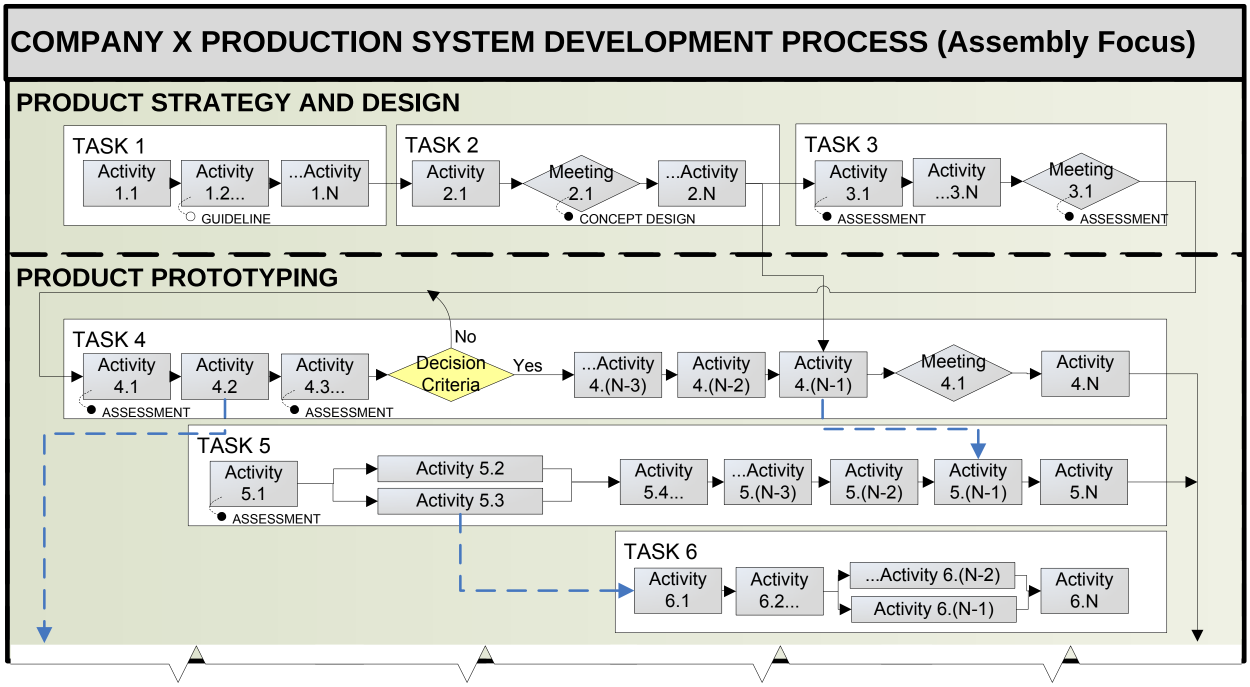

Figure 5: Sample PSDP map for illustrative purposes. This version drilled down into the process details of the high-level PSDP map shown in Figure 4.

3.1.2 Map application trials

This section describes the results from the trial events of applying the map to stimulate organizational change towards proactive ergonomics: 1) map review of HF decision points with the ergonomist and 2) workshops.

3.1.2.1 Determining critical HF decision points with ergonomist

The discussion with the ergonomist around key HF decision points on the PSDP map (key event 7) described in section 2.4.2.1 led to 10 key human factors decision points being identified on the map and several change ideas towards proactive ergonomics (see Table 7). All of the ideas and key points identified occurred in the product stages prior to production, thus confirming the need for embedding human factors considerations early in the design.

Table 7: Summary of key human factors decision points and recommendation ideas which emerged during the process review with the ergonomist.

Key HF decision points in the PSDP by product phase	Ideas for process improvement
PRODUCT STRATEGY AND DESIGN	
1. Product design:	Design for manufacturing (DfM) / assembly (DfA) training
2. DfM/DfA meetings:	Creation and use of DfM/DfA guidelines for standardization
PRODUCT PROTOTYPING	
3. Tool and fixture acquisition:	Consult ergonomist during this process for force, posture and time considerations
4. Prototyping manual assembly time studies:	Creation of database of standards times and HF guidelines; simulation; consult ergonomist during initial process design
5. Development of assembly processes and standard times for manual assembly tasks	Creation of a database of standard times and HF guidelines; consult ergonomist when developing assembly processes
6. Process documentation:	Inclusion of assembly tips for operators in visuals and instructions
PRODUCT MATURITY AND PRODUCTION PLANNING	
7. Production management:	Consult ergonomist on job design; guidelines for operator resourcing
8. Line layout and workstation design:	Design guidelines and checklists
9. Training of assembly operators:	Ergonomics training for managers, designers, and operators
10. Line layout and workstation installation and execution:	Workstation assessment and approval by ergonomist

3.1.2.2 Workshops

After a series of project planning meetings where improvement ideas were presented and discussed (see section 3.1.3.1), "workstation and line layout design" was the topic chosen for the first workshop since the department and scope involved were within the new project lead's control (key event 9). In preparation for this event, the IE took initiative to create a new PSDP map as a tool for participants to identify opportunities for embedding ergonomic considerations in the PSDP – the first of two main objectives of the workshop. The map created by the IE emphasized roles, timelines, documents, and detailed process steps. Its application led to the identification of 17 areas for HF engagement with 35 process improvement ideas.

These 17 areas were developed into sub-projects by areas of engagement in a second workshop (key event 12). Each sub-project was first explained, and then the workshop participants jointly added deliverables, current related initiatives, and resources by department with additional ideas added along the way (e.g. 'education' was a new topic). This activity resulted in 14 defined sub-projects (summarized in Table 8) which were prioritized in terms of impact and effort and scheduled in a draft 3-year timeline. The participants agreed that the research team along with company representatives from the production management, manufacturing engineering, quality, and manufacturing training departments would be the main supporting resources for these projects; and a few other identified stakeholders would also be engaged. This cross-functional resource allocation confirmed the shared stake in the effort by various organizational departments.

Table 8: Summary of sub-projects resulting from Workshop 2

Sub-projects: Areas for HF engagement	Deliverables
1. Design support	1) Design HF score cards / rules to integrate HF aspects.
2. Repair processes	1) Create design for disassembly & repair (DfDR) guide that includes HF aspects.
3. New product release	1) Create HF elements for standard FMEA (note: may share items from score cards in 'Design support' above and link with 'Lessons Learned').
4. Prototype build product development	1) Create risk assessment tool and system/method for application; 2) create guidelines for packaging.
5. Design of assembly tooling & fixtures	1) Integrate HF into tool & fixture checklists; 2) create checklist for tooling for disassembly.
6. Design of assembly processes (preparing for higher volumes)	1) Create HF assembly process guidelines; 2) implement applicable tools (e.g. line balancing); 3) develop rotation strategy and guidelines.
7. Assembly layout	1) Create 'workstation and line layout' guidelines and checklist.
8. Production flow strategy	1) Develop guidelines for achieving optimal production flow strategy.
9. Work instructions	1) Include DfDR issues in work instructions; 2) create HF embedded 'generic' work instructions (as template) and standardize work instructions to include this.
10. Pre-ramp	1) Create checklist for HF as production parameter which includes signoff and audit; 2) design metrics of open issues; 3) integrate HF in quality assurance readiness audit.
11. Maintaining and sustaining	1) Integrate HF into 5S audits and regular process audits.
12. Metrics	1) Establish and review baseline measure for project; 2) develop set of future process metrics; 3) integrate HF with other metrics & indicators.
13. Lessons learned	1) Capture learning at all process stages.
14. Education	1) Implement directed HF training and refreshers by role; 2) create procedure for operators to identify and communicate any HF issues.

3.1.3 Other results

In addition to the workshop outcomes of the identification of process improvement opportunities and the creation of projects for implementing these ideas, there were 2 other main results:

3.1.3.1 Creation of a summary of improvement ideas from discussion with personnel

The author drafted a workshop agenda with a high-level summary of the initial interview (key event 2) and verification meeting (key event 5) data including comments on opportunities for improvement such as organizational silos, lack of organizational learning, varying processes and work environment. The company personnel expressed that these issues were more strategic at upper management level and they preferred to focus more on lower-level process issues. To meet this need, the author re-analyzed the initial interview and verification meeting data for process challenges and improvement ideas as described in section 2.4.1.4. This summary included 167 interview comments regarding challenges and process improvements compiled under the 12 topics of design, equipment, HF training, HF, layout and workstation, learning and feedback, metrics, organization, process, task analysis, training, and transition (see key event 6). The majority of these ideas were revisited and elaborated in the workshops since many of the interview participants were in attendance.

In preparation for the meeting with the new director of engineering (key event 8) and due to confusion expressed with the larger document, the author summarized the low-level summary in a document containing 33 process recommendations under the 6 topics of 1) communication and information flow, 2) lessons learned, 3) HF considerations, 4) manufacturing floor, 5) metrics, and 6) manufacturing training (included in Appendix A); with which the new director expressed agreement. This served as the final summary of the stakeholder recommendations for process improvement made during map creation. The author presented the PSDP map and then used it to illustrate the process points where HF decisions were currently made (from key event 7) on the map in a project planning meeting (key event 9). The 33 process recommendations were then presented and the team discussed the results.

3.1.3.2 Use of the project as a forum for tackling other issues

Another result was the company's initiative to use the project as a means for addressing issues raised within the manufacturing engineering department. Firstly, the ergonomist expressed desire for the project being a medium for addressing a Ministry of Labour report which required the company to create an ergonomics program. Secondly, an internal corrective action report (ICAR) was raised during workshop planning which required the manufacturing engineering department to create a formal process during production line setup and modifications to clearly define responsibilities, communicate status, and review requirements before the start of production. The company used the project's first workshop (key event 10) as a means for resolving this issue by including a second activity creating a workstation design guideline checklist with human factors considerations. 2 separate styles of checklist were created due to different interpretations of the task by the 2 groups of participants. One group first considered elements of workstation and then brainstormed best workstation qualities from operator's perspective; the second listed relevant categories (e.g. equipment, materials, etc.) then brainstormed elements of the workstation and its design for each. The PCs combined these results and categorized them under the 9 categories of: equipment, materials, services, visuals or documentation, tools and fixtures, safety, human factors, process control, and 5S. Under direction from the project lead, this workstation design guideline effort was assigned to the ergonomist. Handoff occurred at the end of that data collection period, resulting in no further observation of this piece.

3.2 Participant responses to mapping

The participant responses to map-related topics are described in 4 sections: 1) responses to map and creation methods, 2) comments on learning and utility as a result of mapping activities, 3) comments on next steps for map, and 4) ideas for other map applications.

3.2.1 Responses to map and creation methods

Responses to the map and creation methods will be presented in 3 sections: 1) general comments, 2) scoping and level of detail, and 3) time/validity trade-off issues.

3.2.1.1 General comments

The project coordinators stated that they believed a fairly complete picture of the PSDP was attained and that the right interview participants were chosen for data collection. Upon first presentation of the map during the verification meetings, the participants expressed positive opinions towards the effort and further agreed that the map was complete. One participant referred to the mapping as *"a big job"* and added *"it's great that somebody's doing it"*. Participants expressed that this map was useful in understanding the process and that it was unique compared to existing company documents.

Although the process map within the PSDP context was described to be unique by several participants, one participant was skeptical towards the novelty of the effort. This participant stated that process maps were not new to the company and that the only new aspect was *“looking at the process with an ergonomics lens”*, commenteding that “*there isn’t much value in the map”* prior to the map application phase. One senior researcher argued, *“The value isn’t the map, it’s what you do with it”* – to which the participant agreed. Following the application of the map in the first workshop, the respondents of the workshop evaluation questionnaires commented that they appreciated the visual nature of the map, the details of product builds, and the ability to understand gaps with the process breakdown.

3.2.1.2 Scoping and level of detail

Scoping and level of detail were ongoing challenges in the project. Participants expressed varying opinions regarding the ‘right’ level of detail of process information on the PSDP map. One participant stated, *“There’s a lot of information here. I need some time to fully understand it; I’m bouncing around”*. In contrast, two participants commented on the need for more details. One participant stated, *“As it stands, it appears to be relatively broad-and would benefit from drilling down in certain areas”*; while another added, *“It's not really wrong but there are more details...You have to be very specific on what you want to zoom into.”* In a discussion with the IE, s/he explained that this was the reason s/he took initiative to create a second map for the first workshop (key event 10): *“we needed to zoom into that small area pretty quickly to be able to identify opportunities and get down to a more detailed level where action items we come up with are executable”*.

In terms of scope, the participants were satisfied with the author's map under the scope of PSDP with a final assembly focus. In comparison to this, several participants commented that the company-created map's scope was too broad and beyond the 'workstation and line layout' workshop theme which caused them confusion also expressed by the university researchers. Furthermore, the scope change in map resulted in the expanded scope of process improvement ideas outside of the originally intended workstation and line layout design theme.

3.2.1.3 Time / validity trade-off

Following map creation, a few participants commented on the lengthy amount of time it took to collect the data used for map creation. Questions were raised on whether or not the method of interviewing and reviewing audio data were "value-added" and necessary. In addition to the time factor, one participant added that participants' opinions may have been biased due to isolation. S/he stated, *"A number of people came in isolated from the process and said this is what I do and this is what I don't like. Getting a group of people in looking at the process would be better."*

A contrast to the methods used by the author was the method used by the IE to create the second form of the PSDP map. In a meeting with the IE, s/he explained that the process map was created in approximately 1 week through discussions with 1 manager and 1 engineer, as well as data found on the company Intranet which was not verified for current applicability. In the workshop questionnaires, respondents commented on the need for verification of the company map to eliminate content errors and prevent confusion during application activities. The IE commented on this by stating, *"I did my map quickly…probably a reason why I didn't validate* *properly"*, and suggested future mapping sessions be done in small groups of people who come prepared to the session with a summary of their tasks.

3.2.2 Comments on learning and utility as a result of mapping

Participant perceptions on learning and map utility as a result of the mapping activities are presented in terms of 1) understanding roles and the PSDP, and 2) understanding HF in the PSDP.

3.2.2.1 Understanding roles and the PSDP

Perceptions of the map's effect on learning more about their roles widely varied for participants. 4 of the 6 process evaluation interview (key event 13) participants responded that the map did not help them learn more about their individual roles, including those who believed this was because they were not directly part of the PSDP. The remaining 2 stated that the mapping activities did help them to learn more about their roles within their own and in relation to other departments. One participant added that the map helped them to visually see their roles in the PSDP and step out of the "silo mentality", while another added: "*We kind of just do what we think we're supposed to do"*.

In addition to thoughts on the map helping stakeholders to better understand their roles, participants expressed positive opinions on how the mapping activities helped them to better understand the PSDP system and the roles of others. One participant stated, *"In the process of creating it you get a better idea of how the system works…until today I didn't really understand how the flow went from real early stages"*. A similar comment was made when the EH&S

manager first reviewed the map, where s/he stated there were early process steps s/he wasn't aware existed. Another participant stated that the map allows users *"to see the big picture and to understand where they can input to get things rectified"*, as well as gain an understanding of upstream/downstream roles, impacts, and interactions. Map creation was called a "valuable exercise" by one participant who admitted that before participating in this effort s/he didn't know the PSDP and other stakeholders' roles as well. In the evaluation discussions (key event 13), all of the interview respondents agreed that the map helped them to better understand the PSDP.

A few participants also commented on the usefulness of the map in determining the current state of the system. One participant stated that mapping was a useful exercise for "matching current practices to perceptions". Another participant admitted that seeing the PSDP on paper allowed him/her to realize that it was slightly different than what was originally thought. Concerns were however raised over missed steps and accuracy, as well as validity dependence on selected interview participants.

3.2.2.2. Understanding HF in the PSDP

In the evaluation interviews (key event 13), several additional comments were made regarding the map's influence on understanding HF within the context of the PSDP. One participant stated that the map creation was "useful to a project understanding" of the goal of HF integration, and that "the project made ergonomics more accepted with everyone". The ergonomist presented the project and map to the EH&S department, and provided the author the following update: *"There were a lot of people that saw the value of the project as a whole. They thought the map was very useful and very detailed!"* A comment was made that the map's perspective was limited to the individuals interviewed; though this participant added that the map was a "big help and good start" since it represented major flow and was a "very effective visual tool" for discussion. As a tool in the workshop, one participant commented that the author's map was too high-level for determining focused HF process improvement ideas as required in a "working-level workshop", while another thought that the use of the company-created map should have been better verified and more targeted at a smaller scope. Other participants expressed that the map was very useful as a reference and guide for detailed discussion around HF concepts and served as "common ground" between the participants. In terms of better understanding HF in the PSDP, participants responded that the map enabled them to better identify points where HF engagement is needed, and was a useful tool in identifying HF potential and determining HF gaps in the process.

3.2.3 Comments on next steps for map

The majority of participants stated that they were unsure of the company's plans on next steps for the map and expressed interest in this information. 3 main points came from thoughts on next steps for the map. Firstly, participants felt that the map should be further validated and formalized before further use. Secondly, participants raised the issue of maintenance required to keep the map content up to date with changing processes as a "living document". One participant suggested that one employee should "own" the map and be responsible for changes; while other participants suggested multiple owners for different sections of the map by responsibility, though they foresaw difficulty in the different owners collaborating on revisions. A third comment was that the map was useful for this application, but planned next steps did not require further use of the map. This point was also made by another participant in earlier discussions of map creation: "*Moving forward, I see it [the map] of limited use. Perhaps it is.*

We could probably go back and do a future state but the benefit may be limited – just have some more paper? We already know what we want to improve." This point contrasted the earlier point of maintaining the map and suggested that maps should be created on more of an "as needed" basis. Opinions of whether the map should be a project tool used "as-needed" versus a process tool maintained as a "living document" differed between participants.

3.2.4 Map application ideas beyond HF integration

Participants raised four main categories of ideas for other possible applications of the PSDP map: 1) process design, 2) training, 3) production management and 4) continuous improvement.

3.2.4.1 Process design

Participants stated that map could be used to design the PSDP through visually identifying design changes. One participant specifically described using the map to help allocate product builds between prototyping and production areas and managing that transition. A second participant expressed the possibility of using the map to identify material handling details and flows between process steps to better understand needs and identify gaps for optimal material handling design. Another idea was using the map to illustrate triggering events between processes in order to design smoother process flows. Lastly, participants suggested use of the map for illustrating what various departments do and "who is responsible for what", to design clearly defined responsibilities and communicate how their actions affect others.

3.2.4.2 Production management

In addition to use in process design, participants described the potential for using the PSDP map as a tool within production management – the department responsible for operator job design and allocation for production. The first idea was using the map for job design; both on the level of job assessments by operator role as well as on a system level of illustrating job rotation and flow strategy as an aid to job enlargement. Another participant suggested the use of the map for allocating and communicating responsibilities by product to document the different product teams. On a strategic planning level, one participant stated that it "would be useful for outsource sites to understand how they're tied in and how to influence, and how it all interlinks and works together." This participant expressed that this application may help to better integrate operations of outsource sites with their facility.

3.2.4.3 Training

The participants of the verification interviews (key event 5) all expressed value in using the PSDP map in training prior to the map application phase. Participants commented that the map would be a good way to introduce new hires to the company, with the possibility of presenting varying levels of details based on the position. One participant suggested that the map be "put on the wall" for reference. In the process evaluation interviews (key event 13), participants added that the map could be presented to new manufacturing engineers coming from different backgrounds (especially automotive manufacturing) for them to better understand process differences compared to electronics manufacturing. One participant who commented that the PSDP map would be "fabulous" as a training tool actually used the author's map to help a new EH&S employee understand the PSDP. S/he stated, "*The map helped him to see the entire* *process beforehand and relate it to the activities seen on the floor tour"*, and expressed that showing the map gave this individual a better understanding than conducting a floor tour alone. Another comment was that the map could be expanded to all of manufacturing (rather than just the assembly focus) and be used for training a larger base of employees.

3.2.4.4 Continuous improvement

The majority of participants described ideas for using the map as a continuous improvement tool. One common idea mentioned was using the map for assessing and optimizing process times and metrics. Other ideas were using the map for identifying process improvements including those related to quality outcomes, and comparing changes in process over time. One participant stated, "*It's good to have it on paper, because I've never looked at it like this to see what we're missing or what we could be doing better."* Another participant expressed the possibility of using the map to complement a value stream mapping assessment of the PSDP.

3.3 Critical thinking in HF integration

The SDE sponsored this university-industry collaboration project to improve the state of human factors considerations in the company's PSDP. S/he expressed an awareness of a gap between device and process designers in terms of HF, and wanted to raise awareness to engineers to have HF considered in engineering. This section describes the observed development in the study participants' understanding of HF and approach to the HF integration problem.

Over the course of the study, participants began with discussing the organization and roles, then drilled down into possibilities of embedding HF considerations within various product development stages, and lastly identified specific action ideas to embed and sustain process improvements. Participant responses are presented and compared at 3 main study points: 1) during initial interviews prior to map creation, 2) during the map creation and verification period, and 3) during and following the map application trials.

3.3.1 HF thinking prior to map creation

In initial discussions with stakeholders, participant responses to HF topics were higher level with the majority of references made to organizational elements; namely 'state of ergonomics', the role of the ergonomist, and HF training.

3.3.1.1 State of ergonomics and ergonomist contributions

Many of the participants expressed belief that the state of ergonomics in the company was reactive. The EH&S manager added that HF seemed to be "after the fact" and not engaged early on, and s/he expressed interest in seeing what information would emerge from the mapping activity. S/he also mentioned that an ergonomics committee did exist in the company in the past but failed due to lack of ownership and belief that "it was just wasting people's time". One participant stated that "ergonomic considerations are more a due diligence thing" and another participant added "more attention to ergonomics is something required here". Many references were made to the automotive industry as several of the participants spoke from past work experiences. In casual conversation, a few stakeholders mentioned the comparatively low forces required in the electronics industry as a possible barrier to justifying ergonomic programs.

A few participants expressed that the scope of the facility ergonomist's responsibilities only covered areas where issues had already occurred. However, two of the participants stated that the addition of the ergonomist to the facility had helped the company become more proactive, resulting in significant changes:

> "We are a lot further now that we've got [the ergonomist] on board to give us guidance. The only thing we had before was EH&S and they've got their skills in many areas of H&S, but having that focus and resource [the ergonomist] has really been a big help over the last while. It's almost like instead of being the last thing you consider, it's the first thing you consider".

3.3.1.2 Training

Training was another central topic initiated by several participants in initial discussion around HF. Arguing that ergonomics training contributed to proactive HF, one participant stated, *"I wouldn't say it's all reactive because your department [EH&S] has organized multiple sessions with the ME's to actually do ergonomics training, and that's preventative"*. This reference to training was a recent initiative where EH&S scheduled ergonomic training sessions from an outside consultant for the in-house engineers. Participants in production management expressed that this ergonomics training to engineers would be beneficial for the managers to have, stating *"That's a huge part of our job...We're ultimately responsible for the well-being of our employees"*. However, another manager added that the usefulness of such training "depends on the detail associated", stating *"it's good to be aware and be able to challenge, but you don't have to be an SME (subject matter expert) yourself"*. S/he believed that it would be better to have higher-level training to just be able to ask pointed questions. In general, the participants were open and receptive to the idea of integrating HF into the PSDP.

3.3.2 HF thinking during map creation and verification

When the verification meetings took place (key event 5) with the created PSDP map a guide for the group, discussions became more pointed and process-oriented in comparison to the comments made in the initial interviews. The discussion on HF integration moved from broad organizational topics, to the focused topic of when HF should first be considered in the PSDP. Participants discussed 3 windows of HF integration opportunity in product development stages: 1) product design, 2) prototyping, and 3) the transition from prototyping to production. However, challenges were identified for each of these points.

3.3.2.1 Opportunity during product design

The first idea was to integrate HF considerations right at the start of product development during the product design stage, since designs are not yet set. A barrier to this was described to be the priority of marketable product designs over assembly and manufacturing concerns during product design stages. One participant stated:

> "We need to be able to give feedback to the product designers. Despite DfM [design for manufacturability] meetings, it's very difficult to give feedback to product designers because they're working under their mandate to come up with a lighter, smaller, faster, cheaper product. But from a manufacturability point of view…this can't be done. So there really is no leverage."

This trade-off in marketability versus manufacturability suggests disconnect between the product design and manufacturing departments due to differing priorities.

3.3.2.2 Opportunity during prototyping

The second discussion point was integrating HF at the following stage of product prototyping where manufacturability considerations are first formally addressed. The interviewed operators expressed their desire to be involved at this stage where the process is in early development and when design decisions are more flexible for 2 reasons: 1) to give them a better understanding of upcoming products and 2) to be able to provide feedback on assembly processes. However, multiple comments were made that prototyping was not a suitable place for integration since here the process is not reflective of the processes in high-volume production. They commented that the main objective at this stage is developing product functionality resulting in many product design and process changes. One participant explained that new assembly issues which emerge in production cannot be predicted in prototyping because of the differences in processes: *"Some things you can't prevent. They [production staff] always claim that (prototyping) is such small-scale that you can't see the issues"*. S/he explained that due to variation in volume and tooling, prototyping processes are not indicative of outcomes on the production floor.

3.3.2.3 Opportunity during transition to production

The last area discussed was HF integration in the transition from prototyping to production. A study participant who was responsible for that transition expressed that this was not a key area for integration since this stage lacked flexibility as designs were already set. S/he explained,

> "There's not too much that we could get back, it's little bits and pieces...I can give feedback to designers, but for future product. Once the product is tooled and everything, you can't change it significantly. They're pretty much onto their next design."

3.3.3 HF thinking during and following map application

Participants identified 3 key process points for HF integration during map creation and verification, and numerous additional process points in the map application trials as described in section 3.1.2. In addition to these process points ideas (i.e. where), participants discussed specific ideas on ways to integrate HF into the PSDP (i.e. how) during and following the PSDP map application trials which are outlined in section 3.3.3.1. Two other outcomes during this period were the observed participant initiative to further HF learning and the emergence of system-level thinking, described in sections 3.3.3.2- 3.3.3.3.

3.3.3.1 Methods for integrating HF into PSDP

During the map application trials period, a shift in focus to planning action occurred. The research team stated that the map served as a tool to "identify HF potential and prioritization" and determine several process gaps, and the consensus was that the identified ideas and ideas for HF integration was sufficient to form an action plan. In these meetings, 3 elements emerged from participant comments: 1) quantification, 2) documentation, and 3) ergonomist empowerment.

1. Quantification.

Quantification of efforts in integrating HF considerations was first emphasized by the project manager from a project perspective:

> "We would like to have a review board forum so that moving forward, we can periodically come back and check the model and process. What is the scope of improvements, what targets haven't we hit yet, what is the target date, what is the action plan for us?"

In the first workshop, one participant added to the point of quantifying improvements by stating, *"Cost is priority. You have to prove to upper management that putting ergonomic designs in place will reduce costs"*. A few participants additionally expressed that human factors should be quantified through process data. Examples were given such as using past injury data to illustrate impacts of lack of integration and embedding HF metrics into the PSDP at key process checkpoints to force stakeholders to maintain HF awareness. In discussions around metrics for quantifying process changes towards embedding HF considerations, the project lead was surprised to learn that HF metrics did not exist and pushed an effort to resolve this gap. This gained awareness resulted in the creation and planning of a metrics-focused sub-project (see Table 7), which draws parallels to the second part of the larger collaborative research and development project.

2. Documentation.

In discussions of training as a solution to giving engineers an awareness to make better design suggestions, one participant argued that it would be more effective for HF to be integrated into the process through process specific guidelines documents. S/he added that instead of implementing general training and approaching the facility ergonomist when issues in specific applications arise, it would be more effective for personnel to refer to clear documentation. S/he explained this point through an example of production system layout processes:

> "We need guidelines from an ergonomic expert point of view; I think this is something missing now. Ergonomics involvement isn't just being there all the time. You should put your expertise in documents across production layout processes. It's not only [the ergonomist's] physical involvement that we need."

3. Ergonomist empowerment.

Many of the participants suggested that the ergonomist be consulted as the human factors subject matter expert at all stages in the PSDP when making design decisions. As a result of discussion in project planning meetings, the ergonomist was 1) granted access to early design processes and encouraged to stay involved and provide input; 2) planned to be a key resource in the majority of the resulting sub-projects; and 3) assigned the lead on other initiatives, such as the design of a workstation and line layout design checklist with integrated human factors considerations (see section 3.1.3.2). In a project planning meeting, a debate arose between two project participants in response to point 1). The first participant questioned the involvement of the ergonomist on layout design decisions because s/he thought it would be disruptive to established and developed concept designs. S/he stated,

> "What would you [the ergonomist] actually do with it? The layout is a result of complex design decisions…You would not have been involved in those series of decisions so you might not understand what those issues are."

The second participant who disagreed with this statement responded, *"take a step back, if s/he is involved then s/he will be aware…we'll involve [the ergonomist] from day one."* Though all participants supported and suggested the involvement of the ergonomist at all stages in the PSDP, this discussion between the participants raised an important point on effective timing for engaging the ergonomist in design decisions in order to effectively integrate HF input where there was still design flexibility. On several occasions during map creation and application, the ergonomist commented that the engineers had been approaching him/her more for ergonomic-related feedback, and thought that this was at least partially due to the knowledge of this collaboration. In the evaluation interviews, the ergonomist commented that "the company is definitely going in the right direction" in terms of proactive ergonomics, and that the project reaffirmed his/her previous vision of the need for proactive HF considerations throughout the PSDP.

3.3.3.2 Initiative to learn about HF

Company personnel in the research team took initiative to attain additional information on HF to improve their knowledge base during the map application trials. The project coordinators enrolled and completed a third-party consultant's webinar on 'world-class' ergonomics process benchmarking, and also attended seminars relating to various HF-related topics in a 3-day conference along with another engineer. The participants then shared their learning experiences with other personnel in the manufacturing engineering department by each preparing and conducting a presentation on various topics. The participants' initiative to gather supplementary information from these external sources to explain the relevance and applicability of the HF integration problem to their organizational departments are central to critical thinking, and demonstrate their reflection on the HF integration problem.

3.3.3.3 Emergence of work system design oriented HF thinking

In addition to the observed initiative to expand HF knowledge, participants demonstrated a rise of expression on the HF integration problem being a work system design issue. During the map application trials, a debate emerged within the research team on whether the project objective was to develop production floor-level process improvements or an ergonomic production system. Several of the key participants argued that the work system design perspective for process improvements was key to sustaining proactive HF, and that the floor-level improvements had limited improvement potential. In the evaluation interviews, one individual retouched on this point and commented that s/he gained an understanding that HF should be viewed from not only the production floor viewpoint, but also from a work system perspective:

> "During the course of the project, we were able to identify HF in various stages; not only the typical understanding that it happens on the production floor. We tried to expand beyond that and understand HF as a tool and as an integral part of the operations, rather than isolated to a specific ergonomic process. This is something new. Companies usually think of ergonomics as a project on the manufacturing shop floor level discounting factors associated in the design, in the finalization of the concept, and in the user friendliness of the product at the end."

Chapter 4 - Discussion

In this chapter, main findings from this thesis are discussed and reinterpreted. The objectives will be revisited in section 4.1 and then considerations for process mapping are discussed in section 4.2. A reflection on the experience of design process mapping as a new ergonomics tool is discussed in section 4.3, and recommendations for future PSDP mapping initiatives are presented in section 4.4. Lastly, a methodological discussion of study limitations and opportunities for future research is provided in section 4.5.

4.1 Study aims and findings

This thesis describes an action research collaboration where the partner company's production system design process was studied and illustrated as a process map through an exploratory approach. As a common industry tool for improving work processes, business process mapping was used as a basis for PSDP mapping (objective 1). Based on the author's review of literature, this was a unique application of business process mapping as process maps are typically applied to existing processes (e.g. Fulscher and Powell, 1999; Keller & Jacka, 1999; Mehta & Fargher, 2005; Rucker, 2000), and have not been previously applied to work system design processes. In this study, process mapping was applied towards improving a production system design process to include proactive ergonomic considerations, and the created process map was tested in group sessions (objective 2). Experiences in testing the map's utility for stimulating organizational change towards proactive HF through various map application activities with company personnel were documented and analyzed to identify aids and barriers and suggest recommendations (objectives 3-4). This approach was generally successful and several opportunities for ergonomic design integration were identified.

4.2 Considerations for process mapping

Based on the results of this thesis and literature references, 4 considerations for process mapping are discussed: 1) data collection methods, 2) scoping and level of detail, 3) style and content and 4) implementation.

4.2.1 Data collection methods

Data for the PSDP map construction were gathered through a combination of field notes and individual interviews with key employees, and the map was verified and revised through group sessions. Since this approach involved in-depth conversations and thorough documentation which took a considerable amount of time to complete, company participants expressed the need for a more efficient approach to data collection. Several study participants recommended a workshop-based mapping approach where a small group of cross-functional employees would jointly create the map in a live discussion session. An example implementation of this approach is Fulscher and Powell's (1999) case study of a process mapping workshop at a mid-size Swiss insurance company. During an intensive 3-day period, two facilitators and five representatives of the organization and business functions used the IDEFO (integrated definition for functional modelling) mapping technique to map an improved process. Derived from the structured analysis and design technique (SADT), IDEFO is a method for modelling the decisions, actions, and activities of an organization or system (Knowledge Based Systems, Inc., 2010). In contrast to the approach taken in this study of beginning with detailed discussions for map creation and the author grouping processes into conceptual process steps, Fulscher and Powell's workshop involved an approach of first mediating abstract process thinking and then moving to process details. Despite these different approaches to data collection, the author's map under study which was created from individual stakeholder maps draws parallels to Fulscher and Powell's (1999) initial map on the first day, appropriately described in their passage:

> "Admittedly, the quality of the process maps developed at this point was far from perfect. Participants had not yet developed a process point of view; that is, they continued to view processes in terms of vertical organizational units rather than horizontally across such units. The results produced so far were an assembly of process parts viewed from different perspectives and brought awkwardly together in one map" (p. 220).

In this study, the stakeholder maps created from various perspectives were pieced together and required the project coordinators to identify levels of details, errors and overlaps to create the integrated PSDP map in key event 3.

Following the creation of a first initial process map, both studies implemented a similar approach of group stakeholder reviews for verification and refinement leading to each study's end map. Fulscher and Powell (1999) described two contributing factors to the perceived success of this process mapping workshop to be "the quality of the participants, and the ability of the group as a whole to maintain focus on the task while preserving the flexibility to adapt to new ideas" (p. 232). In their study, participant collaboration and motivation were observed to be high due to backing of their superiors and that "being chosen to participate was a clear recognition that their ideas and experience were valued" (p. 232). Furthermore, "The facilitators also had considerable authority, since they had been chosen to advise on the design of the new process architecture" (p. 232).

Though Fulscher and Powell's process mapping case study illustrates a successful implementation of this faster approach; the action research and interviewing approach in this study enabled data collection of an additional type of information – tacit knowledge. Many organizations recognize explicit knowledge which is written, stored validated and protected by organizations. In this study, it was observed that many company artifacts where explicit process knowledge was documented were out of date or not well understood. In contrast, tacit knowledge is composed of cognitive (i.e. reasoning schemes) and technical (i.e. know-how, ability, experience) aspects (Renaud et al., 2004). As expressed out by Renaud et al., "*It is undeniable that non formalized knowledge has an influence on decisions made during development . It is part of the frame of reference of innovation teams.*" Some examples of tacit process knowledge identified in this study were heuristics of resourcing assembly activities (i.e. Person A is the most skilled at Job B, effective rotation schedules, etc.), and troubleshooting assembly issues through learning experiences, since past lessons learned were not well documented. Short times to ramp and changing processes were determined to be major working environment components in the current context of electronics assembly, and company personnel admittedly noted that tacit knowledge of the PSDP played a vital role in successful production runs. Furthermore, tacit knowledge was relevant to the design and decision making focus of this process map application in which opportunities for process improvement were identified.

In this study, tacit knowledge was obtained through individual discussions to gather in-depth information, as Renaud et al. (2004) note that tacit knowledge comes from the decision maker's point of view. Though Ambrosini and Bowman (2001) support the interview and mapping approach to obtaining tacit knowledge, they suggest mapping as a group activity to yield additional insight through “inherent group dynamics”. Though this contrasts the approach taken in this study of piecing together composite maps, the author observed that the group verification and application sessions served this purpose and yielded group dialogue and reflection. The observation and interview-based method of data collection in this thesis was time consuming, though it enabled the extraction of tacit PSDP knowledge.

The author recommends starting with a few individual interviews of subject matter experts who have had significant cross-functional exposure to the process scope of focus. These sessions should be digitally recorded for future reference but not transcribed as the author found little value in the time consumption of creating full transcriptions. Rather, notes should be taken with key times of important discussions and topic changes in the audio recording marked for later review. Once an overview of the process is gained along with information about the working environment and tacit knowledge, group mapping sessions should be held. It is advised to hold these activities with reasonable gaps in-between visits (i.e. no greater than 2 weeks) as the author experienced a “moving target” while mapping since processes were constantly changing. A challenge to this may be commitment of company time for several key stakeholders for extended periods of time. It would also be helpful to provide existing process documentation, but this may be difficult to obtain due to confidentiality especially early in the study where trust is not yet established. Furthermore, future PSDP mapping practitioners should ensure process documents are current and accurate, since outdated and inaccurate documents may result in mapping errors as observed in this study.

4.2.2 Scoping and level of detail

Throughout the process mapping and map application activities, several participants expressed varying opinions of scope of process mapping and organizational involvement. During the author's, as well as the company's, mapping activities, 'scope creep' occurred and upstream and downstream processes from the originally agreed upon scope of final assembly were analyzed.

Fulscher and Powell (1999) note that many process mapping events "focus either too narrowly on specific business problems or else attempt to map the entire corporation", and recommend focus on goals on particular events. In contrast, Siha and Saad (2008) recommend that process improvement projects "be carefully chosen and broadly defined and include more activities so that the resulting improvement is more likely to extend throughout the entire business." In this study, some participants felt it would be better to involve a larger range of departmental groups for this reason, while others felt it was best to keep involvement small until progress and recognition were attained. Since this was a first step in the newly formed collaboration with the company, the researchers as well as the project lead were cautious and chose to keep involvement small.

Though the choice of mapping scope is dependent on the complexity of the process of study, the author recommends that the project start with a scope that is clearly defined and not too broad for action-oriented results, which may be difficult in initiatives of larger scope. In terms of organizational involvement, the project should start within the scope of the project owner's domain for participant backing, and only engage outside departments when necessary for specific expert knowledge.

Though merit was expressed in obtaining a ‘big picture’ overview of the PSDP by several participants who stated that such a document didn’t exist, some participants expressed the need to drill down into further details of the process for ‘working’ level of detail. This may be a valuable place to start since this is where participants are most comfortable, which can support initial development of process thinking. However, a challenge to detailed mapping is the greater amount of time and effort required to map greater detail, which is analogous to the speed-accuracy trade off principle (or SATO) of human motor performance (Helander, 2006). Observed by the contrasting mapping methods of the author and the company, inaccuracy of quickly created maps requiring group sessions to fully verify information (upon first exposure) may be counter-productive.

Though thorough sessions of participative map creation may take longer, it was observed to result in increased participant acceptance due to their understanding and awareness of the logic behind mapping. Furthermore, group sessions were observed to take advantage of cross-functional organizational learning. Related elements were observed to be timing and time consumption. Company stakeholders desired regular collaboration without large time gaps between visits, though expressed difficulty in balancing their primary job responsibilities with project commitments. Project scheduling is company dependent, but appeared to be an important determinant in the activities chosen in this study and level of mapping detail.

4.2.3 Style and content

In the created PSDP map, the elements illustrated were process activities, roles, tools, sequence and production area. Process activities were illustrated using flow chart notation with roles and relevant tools noted, and mapped within the relevant production area (or organizational department) through swimlane style (see Figure 5). Service functions which applied in certain production design implementation cases were noted as separate to the process map and illustrated in a separate high-level map (see Figure 4). The company expressed desire to include timelines, but this was difficult information to obtain since varying products and even production runs within a product line had differing and undocumented times. In addition to the difficulty in gathering information on complex scheduling, the author and research team concluded that even if this information was obtained, it would be difficult illustrate in the form of a map. For these reasons, timing and scheduling of PSDP runs may be more appropriate to study through simulation modeling in future studies.

Rising from a similar challenge experienced in their case study, Fulscher and Powell (1999) suggest alternatively focusing on sequence (as implemented in this study) rather than on timelines. The author adds that where it is difficult to obtain timelines, sequences should instead be illustrated for more efficient mapping and that timelines could be added once sequences are determined. In addition, it is recommended that map elements are chosen to be useful to the specific analysis. In this case, information on all aspects was gathered with attempts at illustration in an exploratory nature. This may not be practical or efficient in other projects. Furthermore, service functions were determined to be an important element but did not fit in the PSDP since they occurred on an as-needed basis, thus they should be identified as complementary but separate.

The mapping style taken in this thesis combined flow charts and swimlane diagrams illustrating a system-level view of the PSDP, to a level of detail deemed appropriate by the author and researchers based on the data collection methods used and time available. Other process mapping approaches that are possible but were not explored during this study due to the greater level of detail required include value stream maps (Rother & Shook, 2003), spaghetti diagrams, SIPOC diagrams (Pyzdek & Keller, 2009), and decision trees (Clemen, 1996). These methods may be suitable for use in 'working-level' analyses for targeted process areas. Another category of mapping methods which may be explored is abstract maps with less process focus, such as concept maps (Novak, 1998) and IDEFO notation (Knowledge Based Systems, Inc., 2010). These may be useful in brainstorming activities or analyses of organizational strategy.

4.2.4 Implementation

The 2 PSDP mapping implementation considerations discussed in this section are map application and project management.

4.2.4.1 Map application

The final version of the PSDP created in this study was used as a tool for identifying process improvements in several group settings. In comparing the review session with the ergonomist (key event 7) to the workshop session on workstation and line layout design (key event 10), the first event with fewer participants and more focused objectives resulted in a smoother event with less perceived frustration and confusion. A lesson learned is that workshops should have a few well defined and related objectives which provide the participants with sufficient time to reflect and contribute to meaningful discussions. Another factor which is expressed by Siah and Saad

(2008) is that practitioners of process mapping improvement projects need to "assure the use of the right people in the right project". The facilitator should have domain knowledge and authority for process changes as recommended by Fulscher and Powell (1999), and participants should be selected to have expertise, authority, and management backing. Since PSDP maps may cover a large scope of an organization's processes, the scope and level of detail of the map presented in these sessions should be chosen relative to the scope and goals of the map application sessions, to present only the necessary and relevant information to the participants.

Study participants had mixed opinions on whether the PSDP map should be a dynamic (i.e. owned and continuously updated and applied) or static (i.e. used for a specific analysis and not maintained) document. Challenges to maintaining the map were expressed to be delegation of ownership between cross functional departments and the value-effort tradeoff in covering the large scope of the map. In their empirical study of successful implementations of process mapping improvement projects, Siah and Saad (2008) identify sustainability to be a critical factor and suggest that practitioners not just be satisfied with initial results but rather focus on continuous improvements. They state, *"This can be accomplished by having a structure in place to avoid backsliding, a system of formal problem solving process in place, a consistent focus on improvement activities and long-term measurable objectives which are linked to the improvement efforts"* (p. 791). As learned through this study, the author recommends that the company lead or project sponsor assume responsibility for ensuring sustainability and ongoing development, with support from the lead researchers.

A second factor emphasized by Siah and Saad (2008) is performance measures, which they express as important to be established and used both before, and, after the fact to evaluate outcomes. Maintaining a PSDP map as a dynamic document may serve as a basis for continuous improvement projects and provide a focus for continuous improvement activities. Furthermore, such a map has potential to serve as a performance measure of process changes at key milestones in process improvement projects. This could be done in periodic review similar to the Kaizen approach (Imai, 1986). A third benefit is that periodic map updating activities have potential to support keeping process practices aligned. As described by Lee (2005) and observed in this study, a gap often exists between perceived process and actual practice in companies. On several occasions throughout the study, participants mentioned that they were not aware of aspects of the map and other departmental practices and were surprised by these gaps. The created map served as a reason to step out of their daily 'business-as-usual' thinking and gain a system-level understanding. Furthermore, activities around map elements spurred discussion on process gaps and became forums for identification of process issues and recommendations for improvement.

Whether a map is maintained or kept dynamic is a choice to be made by the users based on their objectives. It is also recommended however that the company be continuously involved in map creation for ongoing rather than handoff of ownership, since in this study participants were observed to be more motivated to use and apply work they had been involved in developing.

4.2.4.2 Project management

Participants provided mainly positive feedback about the project as a whole, and the project gained visibility within the organization. The main challenge faced was the unstable project team which resulted in several cycles of realignment between the team with introductions of new participants or change in project ownership. As recommended by Neumann et al. (2009), project leads should be prepared to ensure continuous internal support and succession planning to accommodate personnel changes throughout the change process. The 2 project coordinators in this study served to be what Neumann et al. (2009) describe to be the “political reflective navigators” who maintained ongoing support in the company’s highly dynamic environment, and this role was shown to be highly beneficial to fill in gaps of process changes between researcher visits. It is recommended by the author that project coordinators be assigned as highly involved participants in the project activities as done in this study.

Siha & Saad (2008) identify top management involvement and strategic alignment as other factors crucial to process mapping projects. Both of these factors were not clear to participants in this study and resulted in some confusion. Top management involvement should be what Siha and Saad (2008) describe to be “effective, real, active and clear to all involved employees”, though it may be difficult to attain regular meetings due to an increased amount of responsibility as experienced in this study. As suggested by the company participants of this study, management backing of participants should be clear and documented in individual performance goals, and project updates to participants should be provided regularly over the course of the project.

Lastly, the author adds that researchers should avoid the tendency to provide consulting and rather maintain the action research aspect of the project for active stakeholder participation in all project and process developments. Fitgerald & Murphy (1996) note that “culture and mind-set change are required and this can only come from within the company itself rather than from any direct actions which external consultants can take” (p. 4). The participants of this study were more motivated to participate in applications of project work they had been actively involved in compared to work done solely by the researchers as earlier described, and even ended up reprocessing analyses done by the researchers in some cases (e.g. workshop agendas and processing of workshop results).

4.3 Design process maps as new HF tool

This thesis entailed the creation and testing of a design process map as a new tool for process improvement with a focus on ergonomics. Throughout the project, various process improvement ideas were identified. Furthermore, 3 main points of insight into the problem of integrating ergonomic considerations into work system design were gained from discussions with participants:

1. The PSDP involves iterations of design concepts and decisions. Once decisions are made at various design stages, it is difficult to alter designs (see section 3.3.2). The implication for integrating ergonomics is that windows of opportunity for ergonomics changes at various stages of the PSDP which need to be analyzed.
2. Means for integrating ergonomics include quantification of the problem to gain the attention of stakeholders, embedding of ergonomics considerations into process documentation, empowerment of ergonomics practitioners to participate in design designs (section 3.3.3.1), and training of stakeholders on ergonomic concepts (section 3.3.1.2). This provides ideas for ergonomist practitioners to consider in their initiatives.
3. In manufacturing settings, activities are required to get participants accustomed to system-level thinking of ergonomics in contrast to the traditional production floor viewpoint of micro-level physical ergonomics (see section 3.3.3.3). This will increase participant understanding of the PSDP and thus opportunities for identifying process improvements.

This study illustrated proof of principle in usefulness of applying a process mapping tool to ergonomic work system design. This tool serves as a system-level tool in ergonomics science – a gap which has been identified by Wells et al. (2007) since the tools common to engineers and ergonomists are mainly at the individual-level of evaluation. The creation and application of the PSDP map was observed to enable critical human factors thinking towards the company's work system design processes (see section 3.3). This learning supported process improvement idea creation at various points of the project including during map creation, verification, and application the workshops. In addition to stimulating participants to consider the ergonomic viewpoint in design, the ergonomist was given exposure to the tools and processes involved in engineering design decisions. As stated by Wells et al. (2007), if ergonomics practitioners have greater insight into engineering tools that impact exposure, they will "better understand the repercussions of engineering design decisions".

The process focus of the tool enabled discussion on common ground between engineers and the EH&S representatives on ergonomic aspects. Discussions between cross-functional groups were initiated to express opinions and ideas on process aspects and potential courses of action, thus acting as a 'boundary object' (Wenger, 1998). This approach was similar to the approach applied by Seim and Broberg (2010), where a workshop facilitated layout design activity involving a game board and pieces (i.e. the boundary object) "enabled multiple practices to initiate a collaborative design process over an artefact which could be comprehended and interpreted by all participants" (p. 32). These activities act as a communication catalyst and engage key stakeholders to think about their current and future contributions to ergonomic design. Furthermore, these activities make tacit understanding of process steps explicit through discussion forums and map documentation.

As expressed by this study's participants and summarized in the second point of insight above, the author recommends that educational pieces be embedded within mapping activities. Furthermore, there should be cross-functional representation including production stakeholders, as well as the health and safety department. Lastly, the issue of level of map detail is especially relevant to ergonomic considerations. A map at the level created in this study could serve as a tool for macro-ergonomics and a basis for creating more detailed working level maps for ergonomic analyses on a prioritized basis. Several other possible applications for the PSDP map were identified in this study including process design, production management, training, and continuous improvement (see section 3.2.4).

4.4 Recommendations

Based on the presented results and central themes in the discussion section of this thesis, a recommended approach for PSDP map creation and application is provided in (Table 9). These recommendations include points on identifying and implementing process improvements with a focus on HF integration.

Table 9: The author's recommended approach for PSDP map creation and application.

Recommendations for applying the PSDP mapping approach
Step 1: Learn about the company • Have initial discussions with the company lead to kick-off the project and gain a general understanding of the company's operations and culture. • Allocate project coordinators (PCs) who can effectively determine engagements with stakeholders, and whose responsibilities cover the PSDP's engineering and ergonomics aspects. • Conduct 30-minute to 1-hour interviews with the PCs to learn about their differing perspectives, then select 1 or 2 additional interview participants who have experience in a large scope of the PSDP to gain additional information. The interview outline in this study may be used (Table 2).
Step 2: Set the scope of analysis and map • With your gained knowledge about the company from Step 1, jointly define the scope of the study and the map with the company lead including what objectives you would like to achieve.
Step 3: Create and validate the map in group sessions • Plan a series of half day group sessions with the sole objective of creating the PSDP map based on the defined scope from Step 2. Participants should be selected based on cross-functional expertise and authority/knowledge about design decisions in the PSDP. The style and level of detail used in this study (see Figure 4, Figure 5) may be adapted. These sessions should be audio recorded and field notes should be taken. • Following each session, translate the created map (i.e. chart paper form) into a soft copy version using process mapping software. • Validate the created PSDP map through iterations of review and revision. In 1-2 hour group sessions, lead a group review of the map created from the previous session by sequentially walking participants through the documented process steps. Refer to the author's list of 7 elements to consider in mapping (Table 6), and document any errors or additional information on the map. Again, use audio recordings and field notes for reference and revise the soft copy. • Once the company lead, PCs, and participating reviewers agree that the map is valid to a useful level of detail and the intended scope is covered, continue to Step 4.
Step 4: Use the map to identify process improvement ideas • Plan the map application sessions to determine process improvement ideas. Each application session should have a clearly defined structure and purpose, with HF training included if possible (e.g. short researcher lectures). Individual applications can be used for more in-depth focus on specific topics, while group applications can be used to cover larger and more complex scopes. • As in data collection, management and/or PCs should select cross-functional personnel who are subject matter experts in the process scope defined. In addition to this, map application participants should have authority over process changes in order to support implementation of process improvement ideas.
Step 5: Implement process improvement ideas • Compile the process improvement ideas from Step 4 and work with the lead to coordinate the implementation of these ideas. This may be done over small projects, each with a defined scope, resources required, and timeline. Identify opportunities to integrate the project efforts into existing company practices (e.g. existing quality group discussion forums) to improve ease in getting activities underway. Metrics may be designed for these projects to ensure sustainability.
Step 6: Update the map and repeat - *optional* • Host periodic group sessions to identify any updates required (see Step 3) and repeat Steps 4-5.

4.5 Methodological discussion

Limitations of the methodology applied in this thesis (described in Chapter 2) are discussed, as well as areas for future research.

4.5.1 Limitations

There are several factors which limit the findings of this thesis both in terms of study design and PSDP map application. Firstly, the case study approach used may have led to outcomes specific to this case. As expressed by Paper et al. (2001), case studies are appropriate in "new and dynamic areas of research", though rate high on data richness and low on generalizability. Factors specific to this case include the industry collaborators, the university research team, the company as a whole, and the electronics industry itself, as well as other social drivers. Secondly, the research team's instability had affects on directions taken at several key points in the study and may have had impacts on the results. The participants themselves had influence and a different set of people would likely have resulted in different outcomes, though the researchers had minor roles in determining the 'right' people since they were chosen by company representatives. Timing played a major role in project progress, and though several process improvement ideas were identified, the company was ill-equipped to implement these during the course of this study. Lastly, the author's interpretation of action research data and choices in illustrating levels of detail may have involved subjectivity, with no empirical basis for determining appropriate choices.

Despite these limitations, this study served as a pilot test of the PSDP map application concept and does demonstrate in principle that the PSDP has potential as a change tool. Insight can be drawn from the ‘equifinality’ concept in organizational theory “where a system can reach the final state, from different initial conditions and by a variety of different paths” (Gresov & Drazin, 1997, p. 403). There would be many different ways the project could have unfolded through different routes taken, but the value of this study lies in the resulting set of realistic suggestions and lessons learned for integrating HF into process design in the end.

4.5.2 Future research

Since the applied approach was both exploratory and within a specific case study, further research is recommended to extend the results of this study. Different map creation methods may be explored in order to reduce the time required to collect map data, including a workshop or group approach. There is also opportunity to explore different mapping representations including combinations of different layout, elements, and level of detail for various mapping applications and specific initiatives. Other design mapping applications are recommended to be explored which would serve to develop generalizable methods of design process mapping. The author recommends that future studies address the role of IT systems throughout processes and interaction with process design decision making, since this element was not explored in detail within the scope of this study. Another possible application not explored in detail was ‘mapping’ company artifacts for different design processes to integrate explicit knowledge with tacit knowledge. This would be beneficial as a reference for stakeholders, though accuracy of documents should be identified in practice as some may be outdated or no longer used.

In terms of the goal of integrating proactive HF design into production system design processes, future research into other organizational methods and into metrics development for change measurement is recommended. Furthermore, analysis of initiative prioritization and implementation within organizations may give insight into how researchers and industry partners can frame new projects to successfully gain management support and serve mutual objectives. This would contribute to the body of knowledge on action research collaborations and provide practical guidance. Lastly, the outcomes of the work started in this thesis are recommended for future research and follow up for the sustainability and measurability of the HF process improvement ideas. Through action research and close collaboration with company personnel, the sub-projects could be followed to determine aids and barriers to HF integration during implementation.

Trials are needed in many contexts to both explore alternatives in the method and better understand the problem's context. Though this approach successfully led to the identification of opportunities of improvement, the organization must be in a position to capitalize these and follow through with implementation to gain from the PSDP mapping effort at its full potential. A cluster approach of studying many sites at once is a possible alternative that may be explored.

Chapter 5 - Conclusion

Through an action research collaboration with a Canada-based electronics manufacturing company, this thesis explored the use of process mapping as a tool for identifying and coordinating process improvements in a company's production system development process (PSDP). The first objective of this thesis, to explore an approach to applying process mapping as a tool for improving PSDPs with a focus on HF integration, was met through various activities throughout the map creation, verification and application phases of the study. Results showed that an individual interview approach to initial data collection of process design was an effective method for capturing process information that included tacit knowledge, though company participants expressed that group mapping workshops would make more effective use of the company personnel's time. A combination of flow charting and 'swimlane' diagrams was deemed to be the most appropriate style of illustrating the PSDP. The speed-accuracy tradeoff of increased detail and validity being inversely proportional to the speed of work was determined to be an influential factor, in both the level of detail to which the map can be created and the process scope covered. To aid future mapping initiatives, the 7 mapping elements determined in this study should be identified in early stages of future PSDP map creation projects: content errors, map overlap, sequence, information flow and feedback, ergonomist involvement, and opportunities for improvement.

The utility of the PSDP map tool for stimulating organizational change towards proactive HF through the generation of process improvement ideas was investigated as the second objective, and aids and barriers to this approach were identified for the third objective. The results show that the PSDP map was useful in ergonomic work system design as a means of generating process improvement ideas by providing a common ground for discussion between cross-functional company stakeholders. 14 sub-projects were formed by the cross-functional team from a list of improvement ideas, and the creation of a workstation and line layout design checklist for integrating HF was initiated from this effort. Critical thinking with regards to the HF integration problem was observed through changes in participant focus with project development, and the ergonomist was granted increased involvement in process design during the map application activities. In terms of implementation, cross-functional stakeholder involvement was found to be beneficial and project management was crucial in study development. As determined in this study, windows of opportunity for flexibility in ergonomics changes in various stages of the PSDP can be analyzed using this mapping tool. The PSDP mapping approach involves activities around system-level thinking of ergonomics in contrast to the traditional production floor viewpoint of micro-level physical ergonomics, and enables participants to understand the problem of work system design for ergonomic integration on a deeper level. Though the PSDP map may aid in generating process improvement ideas for ergonomics integration, the company must be in a position to implement the ideas attained to achieve maximum benefits of this approach.

Longitudinal observation and analyses of the collaboration served as proof of principle in the potential utility of this novel application of process mapping, which contributes to the lack of system-level tools in ergonomics science. Furthermore, this tool has potential to support other areas such as production management decisions, training, continuous improvement and management of company artifacts. Complementary studies on different map creation methods and mapping representations would support development of the PSDP mapping tool. In order to learn more about sustaining HF changes, future studies should address applications of other organizational change methods, analyses of initiative prioritization and implementation within organizations, and HF-based metrics for measuring process changes.

Appendices

Appendix A: Summary of recommendations

This is a summary of the process recommendations made by various study participants in initial interview and process map verification discussions, which took place between February 18 and November 18, 2009.

- Communication and information flow (7)
  1. Improve communication between prototyping and production on product issues
  2. Find a way to 'cleanly' hand over projects
  3. Find a way to better manage product issues
  4. Improve consistency between departments; remove silos
  5. Make sure all stakeholders have understanding of what's expected
  6. Standardize methods for performing DfA (design for assembly) and DfM (design for manufacturing)
  7. Create a process for tracking action items in pre-build meetings

- Lessons learned (3)
  8. Create way to document past problems in task design for operators
  9. Ensure that manufacturing engineering and production staff have the ability to give feedback to product designers from manufacturing standpoint
  10. Create way to share lessons learned across the factory (currently lessons learned are only program-based, and rely on mixed teams for problem-solving from past experiences)

- HF considerations (5)
  11. Create process to ensure that the ergonomist is involved earlier on in areas such as tooling/ fixturing, activity breakdowns, line balancing and layout
  12. Involve operators in task and workstation design
  13. Provide those involved in equipment selection with ergonomic training
  14. Provide managers with ergonomic training to increase their awareness of operator risk
  15. Create a parallel process to analyze HF during product phases

- Manufacturing floor (9)
  16. Determine packaging processes earlier in PSDP
  17. Increase consideration and accountability at the manufacturing floor level of how the line is supposed to look, and get rid of clutter
  18. Increase consistency in methods between different crews and shifts
  19. Provide solutions for increasing cleanliness and decreasing contamination
  20. Implement flow-checks, standardization, and error-proofing (Poke-Yoke)
  21. Find solution for ensuring operators have all necessary tools available
  22. Keep operators informed of up and coming products and if possible, provide operators with samples of parts when presenting a new product assembly
  23. Get operator feedback on line layouts earlier in the design process
  24. Improve coordination between groups when setting up a new line

- Metrics (5)
  25. Measure to ensure success (i.e. meaningful metrics for the nature of company)
  26. Ensure right people get the right information at the right time
  27. Create metrics which distinguish between leading and lagging indicators
  28. Develop EH&S reports to link injuries to equipment or stations (currently not done)
  29. Create other ergonomic indicators

- Manufacturing training (4)
  30. Develop processes and procedures in manufacturing training to ensure timely training requests
  31. Standardize training processes with each outsourcing partner and each manufacturing engineer
  32. Improve training documentation and processes to capture when process changes require retraining (currently training structure doesn't respond to needs on the floor)
  33. Improve quality of maintenance training to ensure knowledge base is kept up to date and personnel are trained

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