T.C.
MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES IN
PURE AND APPLIED SCIENCES

ANALYSIS OF RELATIONSHIP BETWEEN ERGONOMICS AND QUALITY: APPLICATION OF QUALITY IMPROVEMENT THROUGH ERGONOMICS IN MANUFACTURING INDUSTRY

Oğuzhan ERDİNÇ
(Industrial Engineer, MSc.)

DISSERTATION

FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

IN

INDUSTRIAL ENGINEERING PROGRAMME

SUPERVISOR
Asst.Prof.Dr. Özalp VAYVAY

İSTANBUL 2006

T.C.
MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES IN
PURE AND APPLIED SCIENCES

ANALYSIS OF RELATIONSHIP BETWEEN ERGONOMICS AND QUALITY: APPLICATION OF QUALITY IMPROVEMENT THROUGH ERGONOMICS IN MANUFACTURING INDUSTRY

Oğuzhan ERDİNÇ
(Industrial Engineer, MSc.)
(141200920010101)

DISSERTATION

FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

IN

INDUSTRIAL ENGINEERING PROGRAMME

SUPERVISOR
Asst.Prof.Dr. Özalp VAYVAY

İSTANBUL 2006

MARMARA UNIVERSITY

THE INSTITUTE FOR

GRADUATE STUDIES IN PURE AND APPLIED SCIENCES

ACCEPTANCE AND APPROVAL DOCUMENT

ANALYSIS OF RELATIONSHIP BETWEEN ERGONOMICS AND QUALITY: APPLICATION OF QUALITY IMPROVEMENT THROUGH ERGONOMICS IN MANUFACTURING INDUSTRY

Established committee listed below, on 05.01.2006 and B.30.2.MAR.0.C1.00.00.sek/47 by the *INSTITUTE FOR GRADUATE STUDIES IN PURE AND APPLIED SCIENCES*' Executive Committee, have accepted Mr. Oğuzhan Erdinç's Doctor of Philosophy dissertation, titled as "Analysis of Relationship between Ergonomics and Quality: Application of Quality Improvement through Ergonomics in Manufacturing Industry" in Industrial Engineering Programme.

COMMITTEE

Advisor : Asst. Prof.Dr. Özalp VAYVAY, Marmara University

Member : Prof. Dr. Sami ERCAN, Istanbul Commerce University

Member : Prof. Dr. Ahmet Fahri ÖZOK, Istanbul Technical University

Member : Prof. Dr. Akif EYLER, Marmara University

Member : Prof. Dr. Ercan ÖZTEMEL, Sakarya University

Date of dissertation's defense before the committee : 13.02.2006

APPROVAL

Mr. Oğuzhan ERDİNÇ has satisfactorily completed the requirements for the degree of Doctor of Philosophy in Industrial Engineering Programme at Marmara University. Mr. Oğuzhan ERDİNÇ is eligible to have the degree awarded at our convocation on .... Diploma and transcripts so noted will be available after that date.

Istanbul **Prof.Dr.Adnan AYDIN**

ACKNOWLEDGEMENTS

I devoted more than two years for this dissertation study, which was full of challenges, hard work and experience. I had the privilege of working with wonderful people during my studies. Without their involvement and interest, completion of this dissertation would not be possible.

Above all, I would like to express my deepest gratitude to my supervisor, Assistant Professor Özalp Vayvay, for his guidance, patience and support throughout this study.

I am very indebted to Mustafa Gültepe, CEO of Talu Textile for his valuable support for application in his company. I want to thank to members of Talu Textile; Hülya Çetinkaya, Yusuf Yılmaz and Ahmet Ötgün, for their contributions all along my efforts to complete application part of the study. Their positive approach and friendship inspired me to do my best.

I am grateful to Professor Ahmet Fahri Özok for his valuable guidance and support even in his very busy days.

I would like to express my appreciation to Professor Sami Ercan, for his support since my very first graduate courses in Marmara University and to Associate Professor Yasemin Claire Erensal for sharing her ideas and experience with me generously.

I would like to thank to my commander Colonel Naci UÇAR, who became a role model for me as an officer and manager.

My thanks also go to my beloved wife Yasemin Erdinç for her endless love and patience.

Finally I would like to thank to my family who did their best to bring me up as a good man and a good officer.

March 2006 **Oğuzhan Erdinç**

CONTENTS

PAGE

ÖZET

ERGONOMİ VE KALİTE ARASINDAKİ İLİŞKİNİN ANALİZİ VE ÜRETİM SEKTÖRÜNDE ERGONOMİ YOLUYLA KALİTE İYİLEŞTİRMEYE YÖNELİK BİR UYGULAMA

Bu tez çalışmasının temel amaçları; üretimde ergonomi ve kalite arasındaki ilişkinin incelenmesi, üretim alanında ergonomi ve kalite birleşimini sağlayan, proje düzeyinde ergonomi yoluyla kalite iyileştirme metodolojisinin tasarlanması ve tasarlanan metodolojinin gerçek bir üretim ortamında uygulanmasıdır. Tez konusu, ergonominin kalite iyileştirme aracı olarak kullanımına yönelik bir metodolojiye duyulan ihtiyacı ve üretimde ergonomi-kalite birleşiminin sonuçlarını sayısal ve somut olarak gösteren uygulamalı çalışmaların eksikliğini gidermek amacıyla seçilmiştir. Tez çalışması ile yukarıda belirtilen amaçlara yönelik sonuçlar elde edilmiştir.

1. Bölümde tez çalışmasının amaçları ortaya konmuş ve literatürde bu konuya duyulan gereksinim açıklanmıştır. 2. Bölüm, ergonomi ve kalite ilişkisi konusunda, geniş bir literatür taramasına dayanan derin kavramsal çalışmaları içermektedir. Üretimde ergonomi ve kalite birleşiminin olumlu sonuçları ile ergonominin Toplam Kalite Yönetimi, ISO 9001:2000 ve EFQM Mükemmellik modelindeki yeri kavramsal çalışmanın odak noktalarıdır. Ergonominin kalite iyileştirmeye yönelik kullanımını ortaya koyan uygulamalı çalışmalar incelenmiş ve bu bölümde sunulmuştur. Sonuç olarak; ergonomi ve kalitenin üretimde birbirini tamamlayan, insanın merkezi rolü, sürekli iyileştirme yaklaşımı, insan hatasının azaltılmasının önemi, benzer analiz araç ve yöntemlerinin kullanılması gibi bir çok yönden etkileşim gösteren kavramlar olduğu değerlendirilmiştir. Ergonomi ve kalitenin başarıyla ilişkilendirilmesi yoluyla, üretimde yüksek kalite performansı sağlanabileceği öngörülmüştür.

3. Bölümde, ergonominin kalite iyileştirme odaklı kullanımı incelenmiş ve üretim alanında proje düzeyi iyileştirme çalışmalarında uygulanabilecek; Ergonomi Yoluyla Kalite İyileştirme (EYKİ) metodolojisi oluşturulmuştur.

EYKİ metodolojisinin ön koşulları, temel öğeleri ve kavramsal çerçevesi bu bölümde sunulmuştur.

4. Bölümde EYKİ metodolojisinin tekstil üretiminde uygulaması anlatılmıştır. EYKİ metodoloisinin planlama, analiz ve geliştirme safhaları açıklanmış, analiz araç ve yöntemleri ayrıntılı olarak tanıtılmıştır. Ergonomik risk/problem düzeyi ile kalite performansı ergonomik geliştirmeden önce ve sonra analiz edilmiştir. Katılımcı bir yaklaşım benimsenmiş, çalışanlar uygulamada geniş rol almışlardır. Etkili katılım ve iletişim uygulamanın başarısına olumlu katkıda bulunmuştur. Ergonomik risk ve problemlerin analizinde, tez çalışması için özgün oarak tasarlanan Ergonomik Risk Analizi (ERA) anketi ve gözlemsel/subjektif bir risk değerlendirme metodu olan Quick Exposure Check (QEC) uygulanmıştır. Ergonomik geliştirme olarak; dikim operatörlerine ergonomi eğitimi verilmesi ve sağlıklı çalışma yöntemleri el kitabı dağıtılması, makinelere doğru çalışma duruşu resminin yerleştirilmesi, çalışma yeri düzenlemeleri ve masalara eğim verilmesi safhalar halinde uygulanmıştır. ERA Anketi ve QEC analizi, ergonomik geliştirmelerden sonra tekrarlanmış, ergonomik risklerde anlamlı azalmalar görülmüştür. Kalite göstergesi olarak dikim operatörü kaynaklı hatalar alınmış, ergonomik geliştirmelerden sonra bu hataların anlamlı olarak azaldığı tespit edilmiştir.

5. Bölümde tezin sonuçları tartışılmış ve öneriler sunulmuştur. Uygulama sonuçları, ergonomik geliştirmelerin üretim kalitesini iyileştirdiğini göstermiştir. Tezin bir çok yönden literatüre katkı sağlayacağı değerlendirilmektedir; literatür taraması ile geniş bir kavramsal çalışma oluşmuş, ergonomi yoluyla kalite iyileştirmeye yönelik yeni bir metodoloji geliştirilmiş, metodolojinin geçerliliği, daha önce literatürde incelenmeyen tekstil üretimindeki sayısal bir uygulama ile ortaya konmuş, akademik literature yeni giren QEC metodu dikim sürecinde uygulanmıştır.

Tezin akademik değeri, yayınlarla desteklenmiştir. Kavramsal çalışma YA/EM'2004 ulusal kongresinde sunulmuştur. Ergonominin ISO 9001:2000 sistemi ile ilişkisi IMS'2004 uluslararası sempozyumunda sunulmuştur. Bu çalışma Production Planning and Control dergisinde yayınlanmak üzere seçilmiş olup, halen incelenmektedir. QEC metodunun uygulamasını içeren bir makale Human Factors and Ergonomics in Manufacturing dergisine gönderilmiş olup, halen incelenmektedir. EYKİ metodolojisini içeren bir çalışma İTÜ'de gerçekleştirilecek olan 11. Ergonomi Kongresinde sunulmak üzere kabul edilmiştir.

Mart 2006 **Oğuzhan Erdinç**

ABSTRACT

ANALYSIS OF RELATIONSHIP BETWEEN ERGONOMICS AND QUALITY: APPLICATION OF QUALITY IMPROVEMENT THROUGH ERGONOMICS IN MANUFACTURING INDUSTRY

Objectives of this dissertation study were threefold; to elaborate conceptual relationship between ergonomics and quality in manufacturing context, to develop a project-level quality improvement methodology which integrates ergonomics with quality and to carry out application of this methodology in a natural manufacturing environment. Motivation for present study was the need of a methodology which employed ergonomics as a quality improvement tool and paucity of applications which clearly demonstrated outcomes of integrating ergonomics and quality in manufacturing industry. Present study addressed to all of these specified objectives.

In Chapter I, objectives were set forth and need for present research was clarified explicitly. Chapter II included a profound conceptual analysis of the relationship between ergonomics and quality based upon a broad literature review. Positive outcomes of linking ergonomics with quality in manufacturing, role of ergonomics in Total Quality Management, ISO 9001:2000 and EFQM Excellence Model were focal points of conceptual research. Case studies which demonstrated use of ergonomics for quality improvement were elaborated. It was concluded that ergonomics and quality were supplementary concepts that interact at; essential role of human, continuous improvement approach, importance of human error reduction and use of similar analysis tools and methods. Successful integration of ergonomics and quality posited potential for high quality performance in manufacturing.

In Chapter III, use of ergonomics with quality improvement focus was explored and a staged methodology for project level improvement applications in manufacturing industry; Quality Improvement through Ergonomics (QUITE) was structured. Prerequisite conditions, core elements and conceptual framework of QUITE methodology were proposed.

Chapter IV included application of QUITE methodology in textile industry. Planning, analysis and intervention phases of QUITE methodology were described and analysis tools and methods were introduced in detail. Before/After analysis of exposure to ergonomics risks and problems and quality performance was performed. Participatory approach was adopted and employees were widely involved in application. Effective participation and communication were key factors that facilitated success of application. Ergonomics Risk Analysis (ERA) questionnaire, particularly designed for present research and Quick Exposure Check (QEC), an observational/subjective risk assessment method were used for ergonomics analysis. Ergonomics training, introduction of correct work methods manual to sewing operators, installation of correct work posture figure on machines, several workstation adjustments and tilting sewing machines were gradually undertaken as a set of ergonomics interventions. ERA questionnaire and QEC were replicated after interventions and significant reductions in ergonomics risks were identified. Quality improvement was monitored via sewing-operator-related deficiencies and it was found that quality deficiencies were significantly reduced after ergonomics interventions. Application results afforded ample evidence that quality could be improved through ergonomics practices in manufacturing industry.

Chapter V concluded dissertation study. Results of the study were discussed and further recommendations were proposed. Present study was expected to contribute to literature in many respects; conceptual work culminated in compilation and assessment of a vast body of research, a new methodology for quality improvement through ergonomics; QUITE was built and validated through an application in textile manufacturing which was not examined in literature and QEC, a recently published risk assessment tool was used for the ergonomics analysis.

Academic value of dissertation study was supported with publications. Conceptual research was presented in IE/OR'2004 national congress. Interaction of ergonomics with ISO 9001:2000 system was presented in IMS'2004 international symposium. This paper was selected for publication in Production Planning and Control journal and is in review. A paper about QEC application was submitted to Human Factors and Ergonomics in Manufacturing journal and is still in review. Another paper introducing QUITE methodology was accepted for publication in 11th Ergonomics Congress at ITU.

March 2006 **Oğuzhan Erdinç**

CLAIM FOR ORIGINALITY

ANALYSIS OF RELATIONSHIP BETWEEN ERGONOMICS AND QUALITY: APPLICATION OF QUALITY IMPROVEMENT THROUGH ERGONOMICS IN MANUFACTURING INDUSTRY

Ergonomics and quality are two interconnected concepts in manufacturing. Altough relation between ergonomics and quality was reviewed in numerous studies, scarcity of research that demonstrated concrete effects of ergonomics on quality was highlighted in literature. Furthermore, a methodology to employ ergonomics for quality improvement has not been found to date in reviewed literature. Several authors emphasized the need to elaborate and concretize effects of ergonomics on quality performance in manufacturing context.

Present study attempted to address these needs satisfactorily and introduced originalities in many respects. This dissertation study culminated in a broad literature review and vast compilation of relevant studies. Quality improvement through ergonomics (QUITE) methodology was built upon a profound conceptual research which integrated theoretical knowledge with contemporary approaches in ergonomics and quality concepts and provided a clear-cut, well-grounded action plan for labour intensive manufacturing contexts. Application part was undertaken in textile manufacturing, specifically in machine sewing. While reviewed case studies introduced applications from various manufacturing environments, an application in textile manufacturing was contributed to literature by completion of this study.

Analysis of ergonomic risks was performed via Ergonomics Risk Analysis (ERA) questionnaire which was specifically designed for machine sewing task and Quick Exposure Check (QEC), an observational/subjective risk assessment method which was recently validated and published. Application of QEC in machine sewing task contributed to originality of present study. This study is expected to make significant contributions to literature and to shed light to future research on both quality and ergonomics subject areas.

March 2006 Assistant Prof.Dr.Özalp Vayvay Oğuzhan Erdinç

LIST OF SYMBOLS

$	**:** US Dollar
μ	**:** Mean
H	**:** Hyphothesis
p	**:** Critical Significance Value
α	**:** Significance Level
Z	**:** Wilcoxon Sign Rank Test Statistic
F	**:** ANOVA Test Statistic
t	**:** T-test statistic
n	**:** Number of Participants/Batches

ABBREVIATIONS

AEP : Applied Ergonomics Projects
ANOVA : Analysis of Variance
CEO : Chief Executive Officer
CSSM : Continuous Safety Sampling Methodology
CUELA : MS Load Analysis System
CWPR : Correct Work Posture Reminder
EAS : Ergonomics Assurance System
EFQM : European Foundation for Quality Management
ERA : Ergonomics Risk Analysis
FCT : Functional Electrical Test
GEMS : Generic Error Mechanism System
ICET : In-Circuit Electrical Test
MS : Muscoloskeletal
MSD : Muscoloskeletal Disorder
OSHA : Occupational Safety and Health Administration
OWAS : OVACO Work Posture Analysis System
PCA : Printed Circuit Assembly
PCI : Printed Circuit Inspection
QEC : Quick Exposure Check
QUITE : Quality Improvement Through Ergonomics
REBA : Rapid Entire Body Assessment
RULA : Rapid Upper Limb Assessment
SIMPLE : Select, Interpret, Measure, Progress, Learn, Echo methodology
SORD : Sewing-Operator-Related Defects
SORDP : Sewing-Operator-Related Defective Products
SRK : Skill, Rule, Knowledge
TQM : Total Quality Management

TRIZ **:** Theory of Inventive Problem Solving

VOP **:** Visibility of Operation Point

WSR **:** Wilcoxon Sign Rank

LIST OF FIGURES

PAGE

LIST OF TABLES

PAGE

CHAPTER I

INTRODUCTION AND OBJECTIVES

I.1 INTRODUCTION

Two fundamental concepts in industrial context; ergonomics and quality have a multi-faceted relationship which is well worth exploring in that quality can be improved substantially through employment of ergonomics. Since early 90's, relationship between ergonomics and quality has been subjected to a wide body of research (Naderi and Baggerman, 1992, Pipinich *et al*, 1993, Kohn and Friend, 1993, Noro, 1991). Many authors agree that while good ergonomics results in higher quality performance, existing quality systems facilitate ergonomic improvements such as better work conditions or enhanced occupational safety (Drury, 1997, Taveira *et al,* 2003, Eklund, 1997). Ergonomics and quality are considered supplementary rather than separate subject areas (Drury, 2000b, Pipinich *et al*, 1993, Kohn and Friend, 1993). *"Ergonomic improvement"* is considered to be an effective tool for not only improving work conditions, but also quality (Eklund, 1997, Pipinich *et al*, 1993, Lewandowski, 2000).

Relationship between two concepts is implied in definitions. In "Handbook of Human Factors and Ergonomics", Helander, (1997), gives a comprehensive definition for *ergonomics*:

> *"Ergonomics is the scientific discipline concerned with the interaction between humans and artefacts and design of systems where people participate. It deals with design of systems that people use at work and in leisure, tools that are used and procedures and practices. The purpose of design activities is to match systems, jobs, products and environments to the physical and mental abilities and limitations of people."*

Juran and Gryna, in Quality Planning and Analysis, (1993), define quality as follows;

> *"To summarize quality means external and internal customer satisfaction. Product features and freedom from deficiencies are the main determinants of satisfaction."*

Eklund, (1997), propounded that relationship between ergonomics and quality is strong with respect to consequences (i.e. waste, rework are caused by human error, discomfort and health impairments), applications (e.g. product design) and evolution.

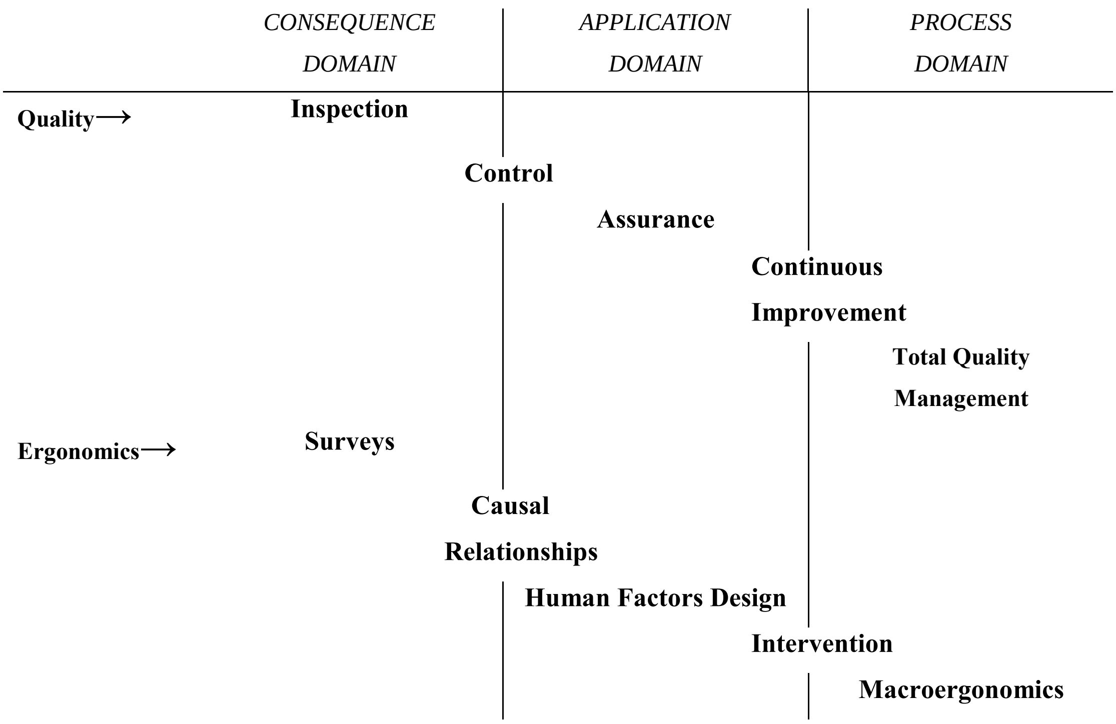

Figure I.1. Aspects of Relationship between Ergonomics and Quality (Eklund, 1997)

Simply put, whilst quality, as defined by Juran, (1988), is "fitness for use", ergonomics is "fitness for user". Thus, both concepts have human in the center (Drury, 2000a). Human has different roles in ergonomics and quality contexts, as "user" (e.g. who uses a product) in former and "customer" (e.g. who buys the product) in latter. Dimensions, outcomes and benefits of interaction between ergonomics and quality in manufacturing context were demonstrated in the figure below.

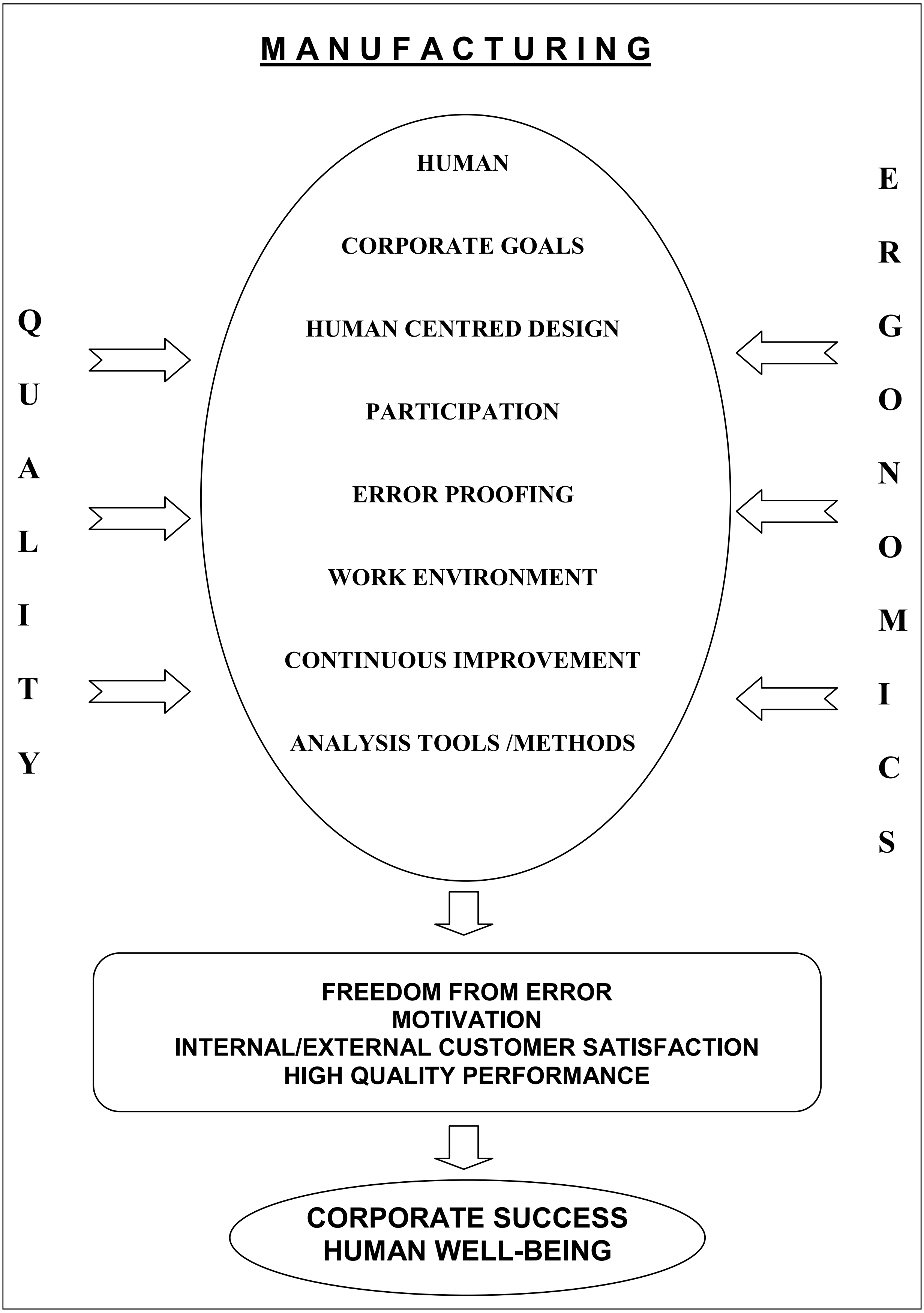

Figure I.2. Interaction between Ergonomics and Quality in Manufacturing Context

As emphasized by number of authors, while several studies in ergonomics and quality literature highlight the relationship between two concepts, experimental investigations that explore influence of ergonomics on quality are scarce (Axelsson, 2000, Drury, 1997, Eklund, 1997, Govindaraju *et al*, 2001, Hagg, 2003, Karapetrovic, 1999, Vayvay and Erdinc, 2004a). Relevant comments of some authors were quoted below.

"The relationship between the quality movement and the ergonomics of job and organization design has been the subject of a number of papers, but relatively few evaluations."(Drury, 1997)

"Paucity of experimental investigations in clearly demonstrating the link between ergonomics and quality suggests that more systematic research needs to be performed to investigate how quality is affected by ergonomic variables such as work area, job design, equipment design, man, machine design, personal interaction, organizational structure and work environment."(Govindaraju et al., 2001)

"Quality improvement of products and services has been a major incentive for the development of industrial production in the industrialised world for several decades. A major point is that poor working conditions are related to quality deficiencies and vice versa. Thus, improved ergonomics is one way of achieving better quality and there is today strong scientific support for such a view (Eklund, 1997) and an increasing awareness in industry of these relationships (Wilson, 1999). However, when reviewing the present documentation of company programmes in ergonomics, there are a few explicitly declared links between ergonomics and quality policies."(Hagg, 2003).

In these respects, objectives of present study were set forth in the following.

I.2 OBJECTIVES

Basic motivation to commence this dissertation study is the lack of a project-level methodology to integrate ergonomics with quality for quality improvement purposes and to undertake an application in natural manufacturing context which would quantify and demonstrate effects of ergonomics on manufacturing quality. In these respects, this study has three objectives:

- To carry out a broad literature survey including conceptual and applied research on quality and ergonomics in manufacturing,
- To develop a project level methodology to bring a systematic approach for quality improvement through ergonomics in manufacturing,
- To apply the developed methodology in natural manufacturing context.

Achievement of these objectives is expected to make significant contributions to both quality and ergonomics literature.

CHAPTER II

LITERATURE SURVEY

II.1 INTERACTION OF ERGONOMICS AND QUALITY IN MANUFACTURING

Given the vast content of quality concept in production, scope of this study was limited to exploration of quality performance in manufacturing in order to construct a reasonable research framework.

Quality performance in manufacturing process has two major determinants; *product quality by design* and *freedom from deficiencies.* Failure to meet a product specification in manufacturing results in a *non-conformity* or a *defect*. Hence, quality in manufacturing turns out to be degree of conformance to determined specifications and *freedom from deficiencies* becomes a key issue in achievement of high quality performance.

A generic measure against deficiencies is inspection of products. However, Deming, (1986), emphasizes as 3rd of 14 points for quality that need for inspection should be eliminated by building quality into manufactuirng processes. Undertaking effective and scientifically well-grounded ergonomics practices is a prerequisite to achieve this end. To build and maintain processes which are *free from deficiencies*, employees should be strongly motivated to perform their tasks as required. Thus, *motivation* is another key issue to attain high quality in manufacturing. In this respect, relationship between ergonomics and quality in manufacturing has two focal points; *freedom from deficiencies* and *motivation.*

Given the quality requirements are identified in manufacturing, *non-conformance to these requirements* stems from an *error* and *freedom from* *deficiencies* becomes *freedom from errors.* Human, the focus of ergonomics is the main source of *error* in quality concept and it is not possible to exclude humans from manufacturing thoroughly (Govindaraju *et al*, 2001). Ergonomics provides necessary body of knowledge about factors affecting human performance and human error. Methods to eliminate root causes of human error can be developed upon this knowledge base and *freedom from error* end in manufacturing can be achieved (Drury, 2000b, Eklund, 1997).

Theoretical exploration of human error is beyond the scope of this study. An important fact for this study is that ergonomic inadequacies in work environment are among major root causes of human error. Severe incidents due to human error such as nuclear power plant breakdowns have necassiated scrutiny of human error in ergonomics science. Trying to prevent human error via administrative methods (e.g. motivation, punishment, training) could yield temporary solutions. However, without elimination of root causes, it is not possible to nullify errors. Thus, tracing down the root causes of errors (e.g. high workload, workstation problems, physical discomfort, task complexity, incorrect color coding) is necessary to design-out errors from manufacturing systems.

Reason and Rasmussen have contributed fundamental theories on human error; SRK (Skill, Rule, Knowledge based actions) theory belonging to former, GEMS (Generic Error Mechanism System) theory to the latter researchers (Park, 1997). These two theories are applicable to analysis of human error in manufacturing.

SRK involves three levels of human performance and human error:

- *Skill based* : Automatic action
- *Rule based*: Actions based on schemata
- *Knowledge based*: Higher level disgnosis type of actions

This theory provides a preliminary insight to human error. GEMS is the extension of SRK theory which prolifarates rules of shifting control between cognitive levels as presented below;

- *Skill based activities*: Routine activities in familiar environments.
- *Rule based activities*: Attention and checks upon progress of action is realized.

- *Knowledge based activities*: Actions require more complex mental process (i.e. novel procedures which is not involved in former two levels.).

Errors are analysed in two divisions in GEMS theory; slips and lapses in skill-based level (i.e.unintentional), and mistakes at rule and knowledge base (i.e. actual erorr of judgement or intention). Based on these theories, Park, (1997), gives a primary list of human error types in industrial context:

- Specified task not performed (e.g.Omission of act, inaccurate performance, wrong timing)
- Commission of erraneous act
- Commission of extraneous act
- Sneak-path, accidental timing of several events for faults

Environment provides cues to people to execute an action (e.g. visual comfort, auditory signals, color codings). If correct cues that facilitate execution of correct actions in intended ways are not provided, error is very likely. Such environments are called "*error-likely*" or "*error-prone*". It is agreed that error-prone conditions lack ergonomic features (Labar, 1996). Designing work environment such that correct cues are provided to employees to perform required tasks without error is an effective way of error prevention, as proposed in aforementioned theories (Douglas and Grout, 2001).

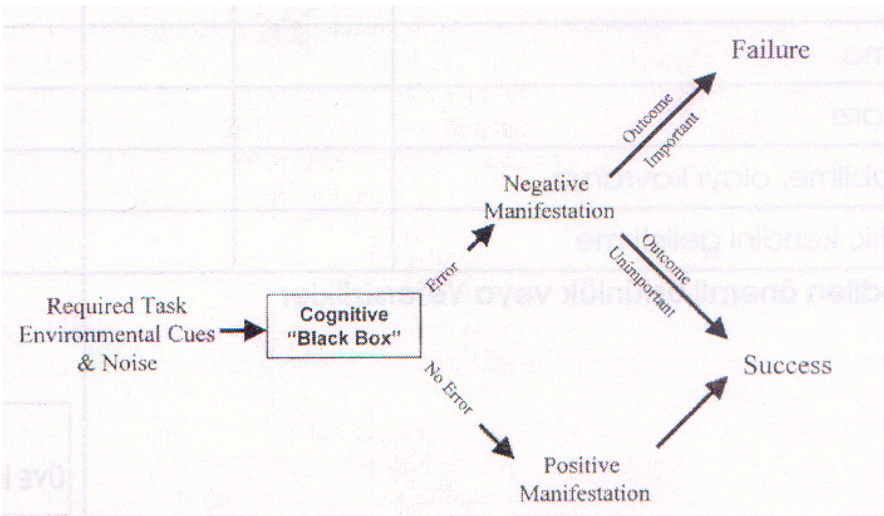

Figure II.1. Work Environment and Human Error (Douglas and Grout, 2001)

Error proofing the work environment requires involvement of ergonomics issues such as maintaining environmental comfort, correct work design, reducing the complexity for mental processes, maintaining compatibility with human expectations and capabilities. Ergonomics in error prevention and reduction is related to design of error-free work environment at large. While error prevention is proactive application of ergonomic design principles, error-reduction can be achieved through eliminating ergonomic problems which comprise the root causes of errors in workplace.

Several authors supported the importance of ergonomics in workplace for quality concerns. Schwind, (1996), suggests that poor quality in manufacturing is a symptom of problems related to ergonomics and it results from pain of worker. Kawecka–Endler, (1996), poses that ergonomically adequate work environment forms the basis for better quality. Eklund, (1997), reported that; adverse working conditions (e.g., insufficient lighting, vibration), repetitiveness, monotonous design of tasks, high postural discomfort and inadequately short cycle times increase human error frequency and quality deficiencies. Drury, (2000a), presents cases in which causes of poor quality were originated from ergonomic problems and improving ergonomics enhanced quality performance. Naderi and Baggerman, (1992), examplified ergonomics problems in industrial settings and associated impact of these problems on quality.

Table II.1. Impact of Ergonomics Problems on Quality (Naderi and Baggerman, 1992)

TYPE OF JOB	DISORDERS	OCCUPATIONAL FACTOR	IMPACT ON QUALITY
Fine hand assembly	Tensynovitis, Carpal Tunnel syndrome, Tendonitis of wrist &shoulder	Repetitive wrist motion, prolonged flexed shoulders, ulnar deviation, arm pronation	Electronic comp. scratch & damage, Misplaced components.
Use of pneumatic screw drivers	Tendonitis, Tenosynovitis, Carpal Tunnel Syndrome	Repetitive wrist motion in combination with excessive grip force, exposure to vibration	Loose screws in parts, damaged products, misaligned screws.
Manual material handling	Thoracic outlet syndrome, shoulder tendonitis, lower back pain	Lifting/lowering, and carrying heavy loads, high frequency lifting/lowering	Dropped or damaged product, parts scratching each other due to poor rack design.
Computer use	Tendonitis of shoulder and wrist, Carpal Tunnel Syndrome	Static restricted posture, arms abducted/flexed, highspeed finger movement	High error rate among data entry personnel, Increased error rate.

Rooney *et al,* (2002), define performance shaping factors as: “anything that affects a worker’s performance of a task within a system”. They include components of work environment in external performance shaping factors and occupational hazards as physiological stressors. According to them; a situation is error likely where "performance shaping factors are not compatible with the capabilities, limitations or needs of an employee". Govindaraju *et al*, (2001) have compiled factors that influence human performance in manufacturing.

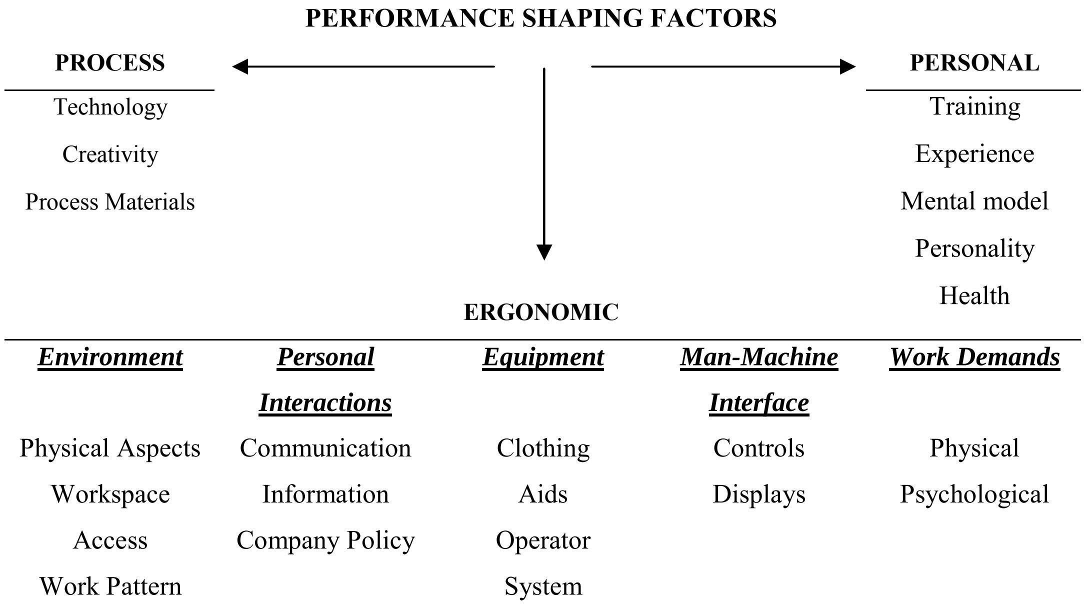

Figure II.2. Performance Shaping Factors in Manufacturing (Govindaraju et al, 2001)

Number of ergonomics-related factors has impact on quality performance. Failure to fit these factors to human would alleviate quality performance. Fuırthermore, these factors should be addressed in quality improvement process. For example, visual inspection, an inherent step of quality control is extensively related with ergonomic factors in that ergonomic inadequacies alleviate visual inspection performance (Megaw, 1979). Previous resarch on integration of ergonomics and quality focused on variety of performance shaping factors. Relevant case studies were elaborated in Section II.3.

Another aspect of relationship between ergonomics and quality is employee motivation. It is suggested by many authors that ergonomic improvements enhance employee motivation which is very crucial to enhance human performance (Öztürk *et al*, 1995, Özok *et al*, 1996). Adverse working conditions would take their toll in high employee turnover and increased error frequency, which diminishes quality performance. In this study motivation is taken as a positive side effect of employing ergonomics for quality improvement rather than a focal issue.

II.2 ERGONOMICS IN QUALITY MANAGEMENT SYSTEMS

II.2.1 Background

Quality is managed and implemented at corporate level through different quality systems such as Total Quality Management (TQM). Ergonomics has certain roles in these quality systems due to its significant influence on quality performance. As substantial contributions of ergonomics to quality surfaced in last decades, involvement of ergonomics in variety of quality management systems has been explored by researchers from both areas (Karapetrovic, 1999, Eklund, 1997, Drury, 2000b).

While ergonomics contributes to quality performance, existing quality systems provide organizational background for ergonomic improvements and innovations (Drury, 1997). Some authors posed that quality systems are very similar in structure to safety management systems which covers occupational safety and health side of ergonomics (Manuele, 1994, Matias and Coelho, 2002). Eklund, (1997), suggested that company-wide discipline imposed by ISO-9000 system forms a basis for ergonomic improvements in workplace. These interactions point to oppurtunities in integrating ergonomics and quality movements in manufacturing.

An important difference between quality and traditional ergonomics is that quality management philosophy is built upon *implementation,* which is a phase in *ergonomics intervention* process in ergonomics concept. The fact that ergonomics solutions have to be accepted both by management and by employees has sparkled participatory approach in ergonomics since early 90’s (Noro, 1991).

Need to address organizational aspects and to gain organizational acceptance for successful implementation of ergonomics improvements has caused interaction of quality management and ergonomics concepts. *Macroergonomics*, concept of constructing ergonomics into organisations has many tenets in common with quality management systems (e.g. employee involvement, teamwork) such as TQM (Drury, 1997, Hendrick, 1991).

Successful quality movements are planned and designed in harmony with strategic objectives of organisations. Thus, via integration of ergonomics with quality movements, ergonomics projects can assume high priorities and can be administered in parallel with corporate strategies and investment plans coming down from strategic goals (Drury, 1997).

In this chapter, interactions of ergonomics and three most wide spread quality management systems; TQM, ISO-9001:2000 and EFQM Business Excellence Model were elaborated conceptually.

II.2.2 Ergonomics in TQM

Most of the studies related to interaction between ergonomics and quality deals with TQM system. As emphasized by numerous authors, core of TQM is human, not quality (Kovancı, 1995, Onur and Özok, 1995), which points to central role of ergonomics in TQM. Success in corporate quality efforts depends on the involvement of human in the center of quality activities and motivation of organisation members who are accepted to be *internal customers* in TQM philosophy. It is believed that as long as internal customers are satisfied with quality of their work life high, corporate quality would be attained, which would incur external customer satisfaction (Lewandowski, 2000). Providing employees with a healthy work environment and work system is a crucial part of *internal customer satisfaction and* is a result of ergonomics efforts. Moreover, ergonomics efforts to improve workplace conditions motivate employees to contribute to companies they work for (Kovancı, 1995).

Noro, (1991), reviewed quality and ergonomics activities in Japan beginning from 70's and he revelaed that remarkable portion of suggestions made by quality circles pertained with ergonomics. For example, quality circle activities with participatory ergonomics approach in Mitsubishi Motor company was reported to result in 224 improvements related to ergonomics practices in motor assembly line (e.g awkward postures, adjusting work surface height, tilting pallet stand) in course of 6 months (Noro, 1991).These improvements were reported to prevent back discomfort. Onur and Özok, (1995), suggested that providing ergonomic working conditions is prerequisite of success in TQM system. Kovancı, (1995), emphasized that successful ergonomics applications in TQM enhance motivation. Some authors pose that TQM creates a suitable organisational structure for systematic ergonomic interventions (Drury, 1997, Karltun *et al*, 1998, Manuele, 1994). Control and minimization of variability in production processes are reported to help to build tasks that are less accident and injury prone (Drury, 1997).

Öztürk *et al*, (1995), investigated effect of ergonomics on TQM in companies located around Bursa via a questionnaire. All of the companies applying TQM and 71 % of companies planning to apply TQM claimed that ergonomic improvements lead to quality improvements. Also, 88 % of companies applying TQM have considered that ergonomic improvements increased the participation of employees in quality system.

Özok *et al*, (1996), carried out applied ergonomics projects (AEP) program and demonstrated how ergonomics can be incorporated into TQM system through a participatory approach. AEP program began with ergonomics training given to employees by Özok. In the end of the program, ergonomic improvements were achieved in 20 items (e.g., task simplification, lifting, machine design). Özok *et al*, (1996), reported that motivation of employees was increased by the opportunity to improve their workplace and to use their own creativity in problem solving during AEP program. Authors pointed out that proportion of suggestions on ergonomics related problems increased by 30 % after AEP program.

Vainio and Mattila, (1996), incorporated occupational safety and health system into TQM system of electrics provision company. Documentation of quality system included safety and health instructions, for example; occupational health principles regarding ergonomics were inserted in quality manual. They reported definite improvement in occupational safety and health issues with that approach.

Small teams of employees are used as operational units in both quality (e.g. quality circles) and ergonomics movements. Teamwork is an efficient and fruitful method for both quality and ergonomics projects (Drury, 1997). Eklund, (1997 and 2000), reports that substantial portion of the problems addressed by quality circles and suggestion schemes pertain with ergonomics (e.g., MS discomfort, pain). Continuous improvement, a core concept in TQM, provides a frame to address occupational health problems such as musculoskeletal disorders (Eklund, 2000). It is suggested that ergonomics projects can be incorporated into TQM system as a part of quality circle applications as well as a separate program (Özok *et al*, 1996). Interaction of ergonomics with TQM system was depicted in figure below.

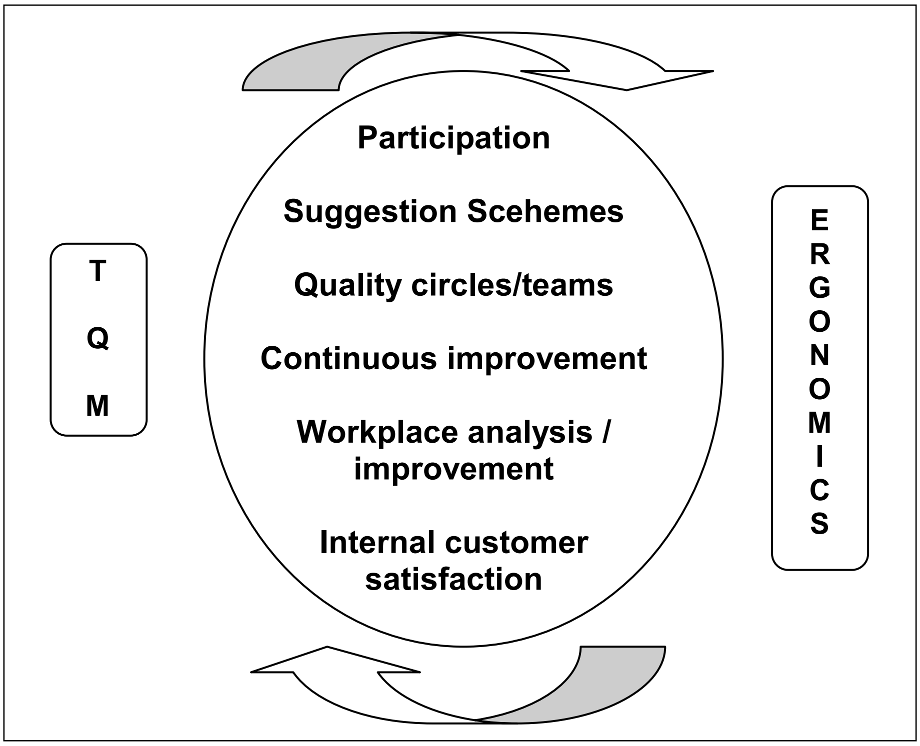

Figure II.3. Interaction of Ergonomics and TQM

II.2.3 Ergonomics in ISO 9000 system

ISO 9000 system has been a widespread way of qualification and competitiveness for companies in manufacturing and service industries. Eklund, (1997), quoted positive effects of ISO 9000 system on various areas as below;

"….better order and method, more positive attitudes towards discussing quality shortcomings, clearer job descriptions and responsibilities, certain workplace improvements, work enrichment as a result of the additional tasks within the quality system and a better understanding of external customer demands".

Not many authors have explored role of ergonomics in ISO 9000 system. Karltun *et al*, (1998) suggested that ISO 9000 could be a starting point for a corporate change which facilitates ergonomic improvements.

According to Karapetrovic (1999), it was implied in ISO 9004 that ergonomics was needed in design of product and processes in order to enhance safety side of quality. He propounded a list of ergonomics issues in ISO 9001:1994 and proposed conceptual framework of Ergonomics Assurance System (EAS), which was designed to integrate ergonomics into ISO 9000 quality management system.

Karltun *et al*, (1998), assessed the effect of ISO 9000 certification process on working conditions in six furniture-making companies in Sweden via questionnaires and interviewes. They found that workplace improvement was not a major part in quality certification and it was not significantly influenced by ISO 9000 process. However, employees expressed their expectancy for a more ergonomic workplace.

By December 15, 2003, ISO 9001:2000 replaced ISO 9000:1994. This revision necessiated recertification for companies which are ISO 9000: 1994 compliants. Among the major differences between ISO 9001:2000 requirements with those of ISO 9000:1994, customer satisfaction focus and need for suitable work environment imply a greater role for ergonomics in the new system.

Assessments regarding ISO 9001:2000 requirements, (QCB, 2001), in which involvement of ergonomics was considered necessary were presented below.

- *5.2 Customer Focus*

Top management shall ensure that customer requirements are determined and are met with the aim of enhancing customer satisfaction.

- *8.2.1 Customer Satisfaction*

As one of the measurements of the performance of the quality management system, the organization shall monitor information relating to customer perception as to whether the organization has met customer requirements. The methods for obtaining and using this information shall be determined

Customer satisfaction is the essence of ISO 9001:2000 system. From manufacturing standpoint customer satisfaction is strongly related with product quality. Ergonomics, being embedded in term "*usability*" is one of the major dimensions of product quality. Juran and Gryna, (1993), proposed "*ease of use*" as one of the product features that provide customer satisfaction. "Ease of use" is associated with ergonomic design of the product to a large extent. A product which does not comply with human expectations fails to satisfy user (Skepper *et al*, 2000).

Importance of ergonomics in product design increases with intensity of human-product interaction and product complexity. As consumer products have become more complex, usability had more influence on satisfaction of users. Jordan, (1998), found that while poor usability (e.g. tuner of a car stereo which is hard to use) caused displeasure, good usability (e.g. easy-to-understand button of a video cassette recorder) resulted in pleasure in using a product. Majority of recommendations given by participants as to how to design plesurable products pertained with usability issues, which was a strong implication for the importance of ergonomics in assuring customer satisfaction.

Variety of new consumer products are advertised to be ergonomic (e.g. new model cars, kitchenware) implying high design quality and user comfort. This tendency supported the fact that ergonomics has become strength from product quality and marketing standpoints. Thus, customer satisfaction focus of ISO 9001:2000 system requires extensive employment of ergonomics in product design. Ergonomic features of products should be evaluated in surveys about customer satisfaction or product quality.

- *6.4. Work Environment*

The organization shall determine and manage the work environment needed to achieve conformity to product requirements.

As strongly supported in literature, this element involves greatest emphasis on ergonomics among all requirements in that fitting work environment to human is a major research field of ergonomics (Matias and Coelho, 2002). Konz, (1992), gives a comprehensive review about components of work environment. Main components of work environment; external stressors (e.g. climate, noise, vibration, air quality, hazardous materials), workstation layout, work design (e.g. work postures, shift planning, physical and mental workload), hygiene and social environment are affective on manufacturing performance and quality. For example; Helander and Burri, (1995), found that illumination was inadequeately low for visual inspection of circuit boards in IBM Austin (i.e. as low as 120 lux in some parts of work place). They increased the illumination by installing fluorescent tubes and using lights that had been kept close for energy conservation. This intervention leaded to an increase in operators' performance of detecting faulty products and in yield of the process.

- *7.5.1. Control of Production and Service Provision*

The organization shall plan and carry out production and service provision under controlled conditions. Controlled conditions shall include, as applicable;

c) the use of suitable equipment;

The element 7.5.1.c implies necessity of employing ergonomics in equipment selection and design. The equipment not only should fit quality concerns (e.g. capacity to process raw material as required by quality specifications), but also should be fitting to user for high quality performance. Use of unsuitable equipment may cause severe health problems for employees (e.g. musculoskeletal disorders, repetitive motion injuries, carpal tunnel syndrome) which lead to high error frequency resulting from discomfort (Schwind, 1996).

Due to considerable cost of hand-wrist injuries, pre-purchase ergonomic assessment of hand-held tools by a special team was performed as part of corporate ergonomics programme in Volvo (Ulfsfalt *et al*, 2003). Ergonomic requirements about the tools were identified by the team and conveyed to suppliers. Tools were purchased after approval of the team. Similar methodologies could be adopted in companies that aim to assure selection of ergonomically suitable equipment for production processes.

- *8.5.1. Continual Improvement*

The organization shall continually improve the effectiveness of the quality management system through the use of the quality policy, quality objectives, audit results, analysis of data, corrective and preventative actions and management review.

- *8.5.2. Corrective Action*

The organization shall take action to eliminate the cause of nonconformities in order to prevent recurrence. Corrective actions shall be appropriate to the effects of the nonconformities encountered.

Quality improvement has a focus on chronic quality problems and enhancing quality performance rather than providing solutions to sporadic quality problems (Juran and Gryna,1993). Ergonomic problems in manufacturing reduce quality performance particularly by increasing human error, discomfort and injury rate. Revision and improvement of ergonomic conditions is likely to yield quality improvement in different terms such as lower defect rate, reduced number of rejected parts, shorter cycle and delivery time (Schwind,1996, Eklund, 1997, Klatte *et al*, 1997, Gonzalez *et al*, 2003). Hence, ergonomic assessments and interventions in manufacturing should be an inherent part of quality improvement process. Case studies on quality improvement through ergonomics were presented in Section II.3.

Interaction of ergonomics with ISO:9001:2000 requirements was demonstrated in the figure below.

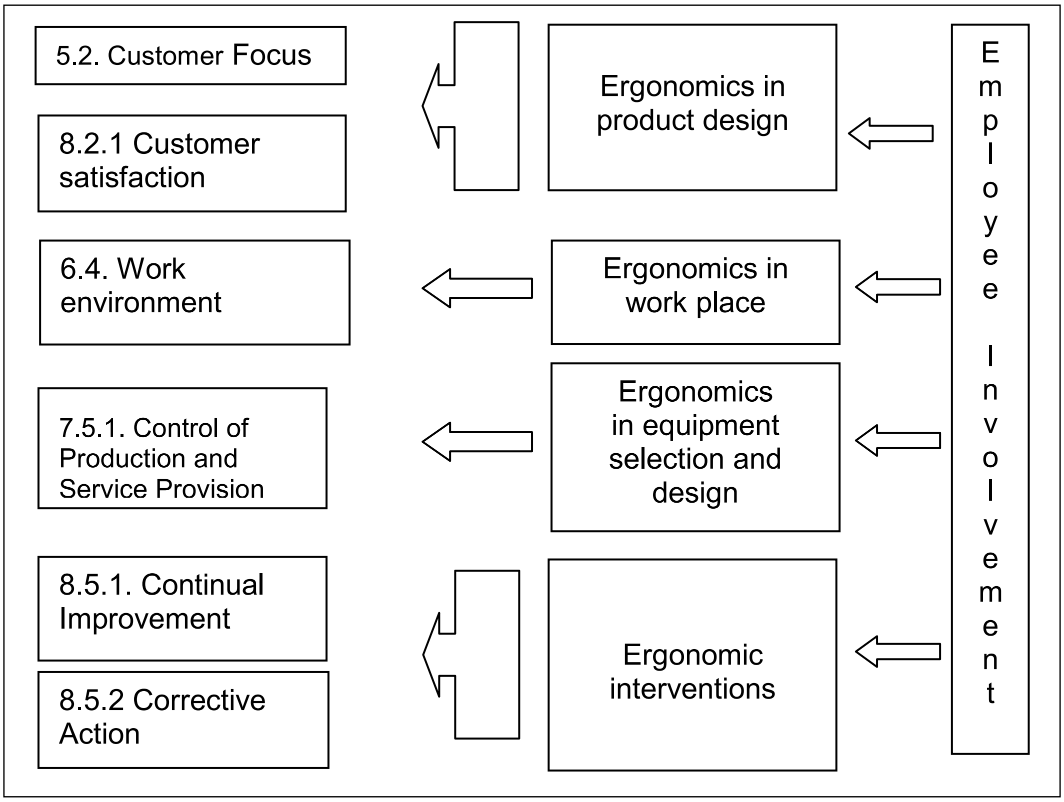

Figure II.4. Interaction of Ergonomics with ISO 9001:2000 Requirements

II.2.4 Ergonomics in EFQM Business Excellence Model

The EFQM Excellence Model was introduced at the beginning of 1992 as the framework for assessing applications for The European Quality Award. It is one of the widely used organisational framework in Europe.

The EFQM Excellence Model is a practical tool to help organisations do this by identifying where they are on the path to Excellence. Self-assessment has wide applicability to organisations at different scales, in the public as well as the private sectors. Organisations are increasingly using outputs from self-assessment as part of their business planning process. Number of organisations which are currently using the model, are proposed to be growing rapidly and exceeds 20,000 across Europe (EFQM official web site, 2003).

The EFQM Excellence Model is a non-prescriptive framework based on nine criteria. Five of these are 'Enablers' and four are 'Results'. The 'Enabler' criteria cover what an organisation does. The 'Results' criteria cover what an organisation achieves.

'Results' are caused by 'Enablers' and feedback from 'Results' help to improve 'Enablers'.

The Model recognises there are many approaches to achieving sustainable excellence in all aspects of performance. The idea of EFQM model is based on the premise that excellent results with respect to Performance, Customers, People and Society are achieved through Leadership driving Policy and Strategy, that is delivered through People Partnerships and Resources, and Processes. The EFQM Model is presented in diagram below:

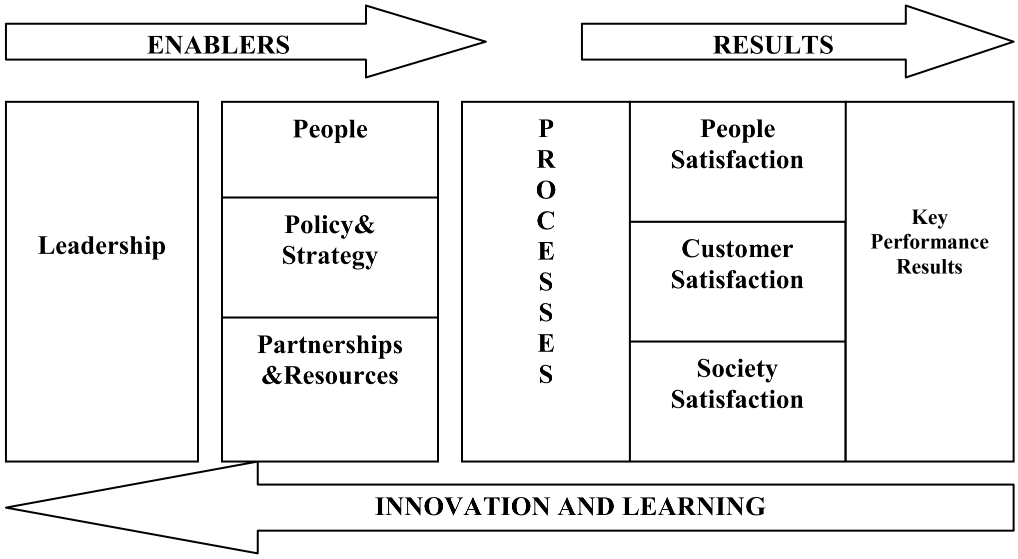

Figure II.5. EFQM Business Excellence Model (EFQM Official Web Site)

The arrows emphasise that innovation and learning help to improve enablers that in turn lead to improved results.The Model's nine boxes represent the criteria against which an organisation's progress towards excellence is assessed. Each of the nine criteria has a definition, which explains the high level meaning of that criterion.

The EFQM model has much in common with other quality systems and ergonomics aspects prevail in system such as; participation, management involvement and support to implementation of model (George *et al*, 2003, Sandbrook, 2001), central role of human in the system. Literature survey showed that role of ergonomics in business excellence model is blurred. There is no clear-cut application of employing ergonomics knowledge or integration of ergonomics into business excellence. One reason may be that EFQM model provides a holistic model of enablers and results while other quality systems posit more concrete procedures.Among four results of the model, “people results” involves the most explicit role of ergonomics. People results relate to satisfaction of people employed in the organizations. These results are to be measured from two aspects; *perception measures* (i.e. gathered through surveys, interviews, questionnaires) and *performance indicators*. People results involve; motivation, involvement, satisfaction, performance, services that organization offers to its people.

To assure employee satisfaction, enablers must be directed towards ergonomics in work place and occupational safety and health issues. Use of ergonomics knowledge is necessary to attain people results. Workplace conditions (e.g. external stressors such as vibration, heat, noise) should be a part of self assessment. Wong and Dahlgaard, (2003), demonstrated that improving work conditions is a part of excellence measurement included in people results. The statement "Accidents and injuries have decreased over the last three years" was selected as one of the ten "most important" statements regarding excellence model applied in a manufacturing company. This statement imply a success from occupational safety standpoint.

However, the role of ergonomics is not well-defined in literature about excellence model. Focal areas of studies are; management, customer, partnerships and processes. It was concluded that ergonomic interventions and ergonomics knowledge is far from central, even a supplementary role for ergonomics is hard to mention. Ergonomics efforts are embedded in improvement movements. Literature on EFQM excellence model, even case studies lack concretenes, and in depth explorations. However, ergonomics knowledge shows that, there exist points in excellence model that necessiate involvement of ergonomics. Interaction of ergonomics with EFQM model is shown in the diagram below.

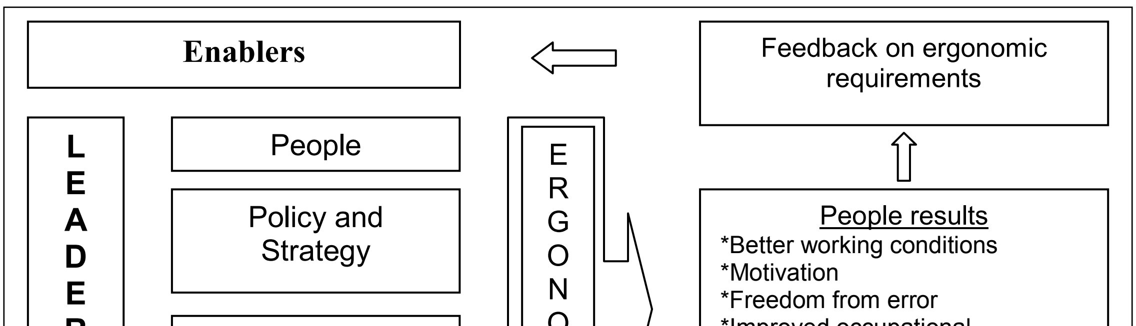

Figure II.6. Interaction of Ergonomics with EFQM Business Excellence Model

II.3 REVIEW OF CASE STUDIES

II.3.1 Case 1: Quality improvement via RULA

Gonzalez *et al, (2003)*, demonstrated that reduction in ergonomic problems enhanced quality performance in an IS0-9002-certified metal product manufacturing company. They interviewed with workers and selected folding task for ergonomics analysis due to severity of ergonomics problems. Folding operation was videotaped and Rapid Upper Limb Assessment (RULA, McAtamney and Corlett, 1993) was conducted through video analysis. Quality data; proportion of rejected and reprocessed parts per lot recorded for two successive months. New procedures were implemented to tasks RULA point of which was higher than 5. RULA points were observed to decrease in new procedures which enabled workers to perform tasks more comfortably. Quality data showed that proportion of rejected and reprocessed parts were reduced by 45 % and 22 % respectively after ergonomics intervention.

II.3.2 Case 2: Ergonomic problems and quality deficiencies

Eklund, (1995), examined relationship between ergonomics and quality in a Swedish car assembly plant. Workers were interviewed about ergonomics problems and tasks with ergonomics problems were reported to cause fatique and physical discomfort. 58 Tasks were found to involve three types of ergonomics problems; physical demand, designs involving difficult assembly and phsychological demand. Ergonomically demanding tasks were videotaped and assessed by an ergonomist and physiotherapist of company. Deficiencies and remarks were used as quality indicators. Deficiency data was gathered from adjustment and assembly departments. Quality inspectors of departments were interviewed about quality problems in ergonomically demanding tasks.

Statistical analysis showed that relative risk of quality deficiency in ergonomically demanding tasks was nearly three folds of other tasks. 66 % of ergonomically demanding tasks were found to involve quality deficiency and "*designs involving difficult assembly*" accounted for the largest proportion of quality deficiencies. Although limited to problem identification and analysis due to plant close-down, this study demonstrated potential positive outcomes of integrating ergonomics and quality in manufacturing.

II.3.3 Case 3: Quality improvement through ergonomics interventions

Yeow and Sen, (2003), conducted a set of ergonomic interventions in a Printed Circuit Assembly (PCA) factory. Their primary objective was to improve work conditions in order to attain higher product quality and productivity.

Among seven manufacturing tasks they elaborated In-Circuit Electrical Test (ICET) and Functional Electrical Test (FCT). They started with a plant walk-through to interview with and observe employees performing ICET and FCT processes. They obtained and analyzed quality performance data (e.g. PCA board defect percentage, cost of board returns). Major ergonomic problems they identified were; poor workstation design, mix-up of tested and untested boards in ICET process, missing / incorrect test steps in FCT process and weakness in operators' training and unclear pass / fail criteria for Printed Circuit Inspection (PCI) in FCT process. They conducted a questionnaire with all operators addressing workstation design, work process, work environment, work problems, quality, productivity, occupational safety and health, training, feed back and time constraints. They applied video analysis to ICET and FCT processes.

At the onset of study, percentage of board defects (i.e. 5.2 ± 0.5 %) was substantially higher than the customer expectations (i.e. 0.1 %) and yearly cost due to customer returns of defective products was 0.5 $ million.

They improved workstation design such that operators could have ample space to rest their arms. In FCT process a projector is used for visual inspection. They put this projector into a black box, reduced ambient illumination which was blurring the vision and as a result visual inspection performance was improved. Tested and untested boards were placed in separate trays. Untested boards were not sent to customers afterwards and defect percentage rate at customers' site was reduced by 3.0 %. To clarify pass/fail conditons of the boards, instead of written instructions, ergonomic reference colour samples were put on the screen where visual inspection of boards was done.

Consequently, savings of 574 560 $ on the average yearly rejection cost due to customer returns of defective board was realized and customer satisfaction was increased.

II.3.4 Case 4: Effect of posture and line pace on error rate

Lin *et al,* (2001), investigated the effect of posture and line pace on error rate in two disposable camera assembly lines (i.e. A being nonautomated, B semiautomated). Quality measure in the company was number of defective cameras (i.e. camera that fails inspection). Count of errors per week was used as the performance measure in the study. Actual time required to complete the task and postural stress were ergonomic variables. Time stress was considered to be a major source of human error in manufacturing systems. Line processes were videotaped and postural stress over back, neck, wrists and shoulders were measured by zone analysis method. Results of the regression analysis showed that more time required to complete the task (i.e. higher time stress) and higher posture analysis scores (i.e. worse posture) would cause higher error rate in manufacturing processes.

II.3.5 Case 5: Applied Ergonomics Projects (AEP) in TQM

Özok *et al*, (1996) implemented Apllied Ergonomics Projects (AEP) in SIMKO within TQM system in order to shape company culture with human focus. Initially, employees were given 30 hours basic ergonomics training by Özok. Subsequently, 37 ergonomics projects were undertaken by teams of 2-5 employees. Projects included improvements related to industrial ergonomics such as; table design, hand tool usage and heavy manual handling. AEP movement was reported to lead employees focus on their work environment. Extensive participation of employees in problem solving process differentiated AEP from typical company activities. Numerous positive outcomes of AEP were reported by employees; enhanced motivation through higher self confidence and initiative, creativity, adoption of scientific approach and group dynamism in problem solving, enhanced consciousness about occupational health and environmental concepts, behavioral change towards compliance. While employees rated continuous improvement, creative thinking and training as most useful contributions of AEP, white collar company members rated training to solve problems in work place, conscious to own work place and contributions to quality as most useful benefits of AEP. It was futher reported that number of suggestions pertinent with ergonomics issues was increased by 30 % after AEP. Application of AEP demonstrated importance of participation and training in quality improvement through ergonomics.

II.4 BACKGROUND FOR RESEARCH

Literature survey revealed that majority of relevant studies has concentrated on conceptual aspects of integrating ergonomics with quality such as role of ergonomics in TQM (Eklund, 2000, Özok *et al*, 1996, Vainio and Mattila, 1996). On the other hand, majority of reviewed applied studies yielded in various outcomes other than improved manufacturing quality, such as increase in suggestions, motivation, productivity or reduction in quality costs (Özok *et al*, 1996, Yeow and Sen, 2003). Although authors emphasized need for systematic approach to link ergonomics and quality (Govindaraju *et al*, 1999, Hagg, 2003), solely Axelsson, (2000), has introduced a particular methodology.

His methodology, acronymed SIMPLE, involved a six-step framework (i.e. Select, Interpret, Measure, Progress, Learn, Echo) and proposedly targeted developmental learning which was to result in ergonomics and quality improvements (Axelsson, 2000). It was considered that, SIMPLE methodology weightly dealt with conceptual aspects of integration between ergonomics and quality rather than introducing explicit practices which left proposed need for a clear-cut methodology to obtain concrete quality improvement outcomes through ergonomics unsatisfied.

In these respects, different from studies in literature, present study sought to culminate in a well-defined, project level methodology to employ ergonomics for quality improvement in manufacturing context. A staged approach was adopted in developing this methodology which was structured such that participation and communication, two crucial organizational success factors (Macleod, 1995) would be involved throughout application, implementation in variety of labour intensive manufacturing environments would be possible and effects of ergonomics interventions on quality improvement would be concretely evaluated. Undertaking this methodology in a natural manufacturing environment formed application part of present study. It was considered that conceptual research, introduction and application of methodology for quality improvement through ergonomics would quide researchers for further applications and explorations of relationship between ergonomics and quality.

CHAPTER III

CONCEPTUAL FRAMEWORK OF QUALITY IMPROVEMENT THROUGH ERGONOMICS (QUITE) METHODOLOGY

III.1. QUALITY IMPROVEMENT AND ERGONOMICS

Quality improvement targets chronic quality problems and enhancement of current quality performance rather than providing solutions to sporadic quality problems. As quoted below by Juran and Gryna, (1993), quality improvement influences present quality performance:

"The costs associated with poor quality are due to both sporadic and chronic quality problems. A sporadic problem is a sudden, adverse change in the status quo, which requires remedy through restoring the status quo. A chronic problem is a long-standing adverse situaiton which requires remedy through changing the status quo"

Quality improvement approach proposed by Juran and Gryna, (1993), was demonstrated in the figure below.

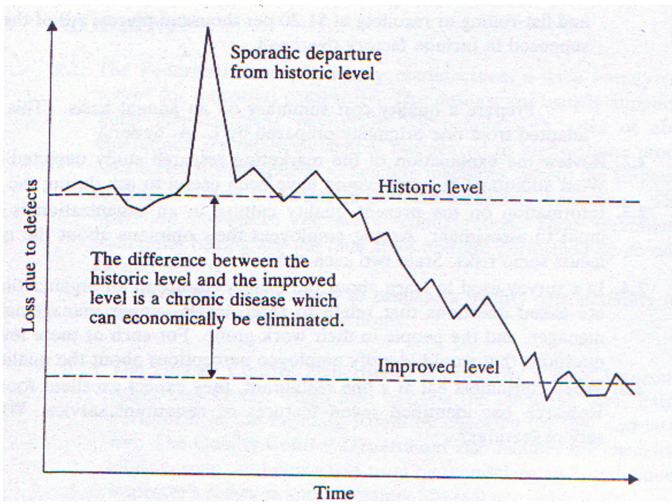

Figure III.1. Quality Improvement Approach (Juran and Gryna, 1993)

Furthermore, Adam and Foster, (2000), proposed a contingency based quality improvement model as shown below.

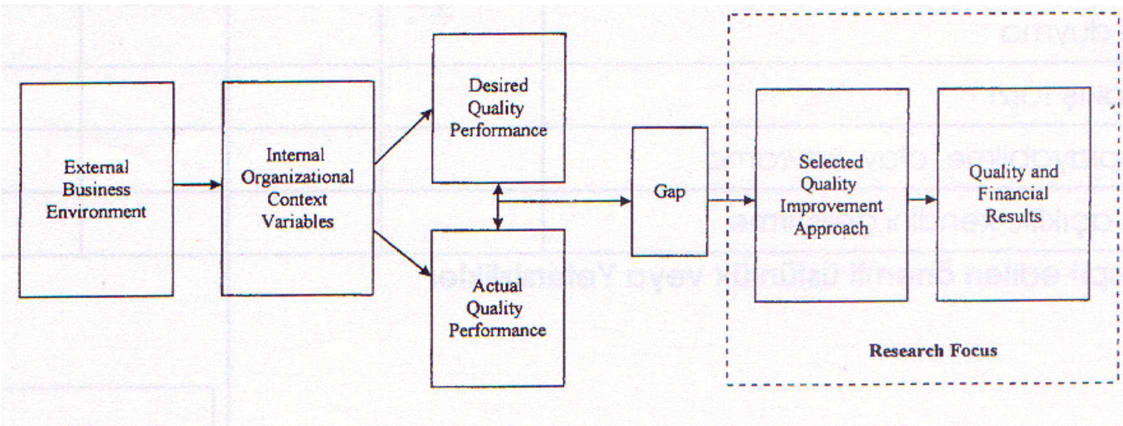

Figure III.2. Contingency Based Quality Improvement Model (Adam and Foster, 2000)

In model proposed by Adam and Foster, (2000), quality improvement is an attempt to close the gap between desired and actual quality performance. Within this model, ergonomics in work environment should be dealt with in "*internal organizational context variables*" concerning manufacturing context. Further employment of ergonomics should be concerned in "*research focus*" part of the model.

As explored in earlier chapters and examplified in case studies, correct integration of ergonomics and quality could result in a win-win situation (Axelsson, 2000). Noro, (1991), propounded that while ergonomics improvements can be achieved by employing quality improvement tools such as Pareto and Fishbone diagram, quality can be improved via better ergonomic conditions. If a quality system is to be built from a scratch, the best method is to involve ergonomics in early stages of establishing corporate goals, organisational structure, and manufacturing systems. In order to improve quality within an existing system, ergonomics should be mounted upon quality structure. Two major paths of quality improvement can be mentioned in manufacturing.

- Improving quality in product design with more preferable features that enhance customer satisfaction,
- Improving conformance to quality specifications in manufacturing process by reducing human error.

As to product design, ergonomics can be used in designing more user friendly and safe products. This line of quality improvement is out of the scope of this dissertation. This study focuses upon use of ergonomics in workplace to reduce manufacturing error and to increase compliance with quality requirements. Effect of ergonomics in quality improvement is depicted in the figure below.

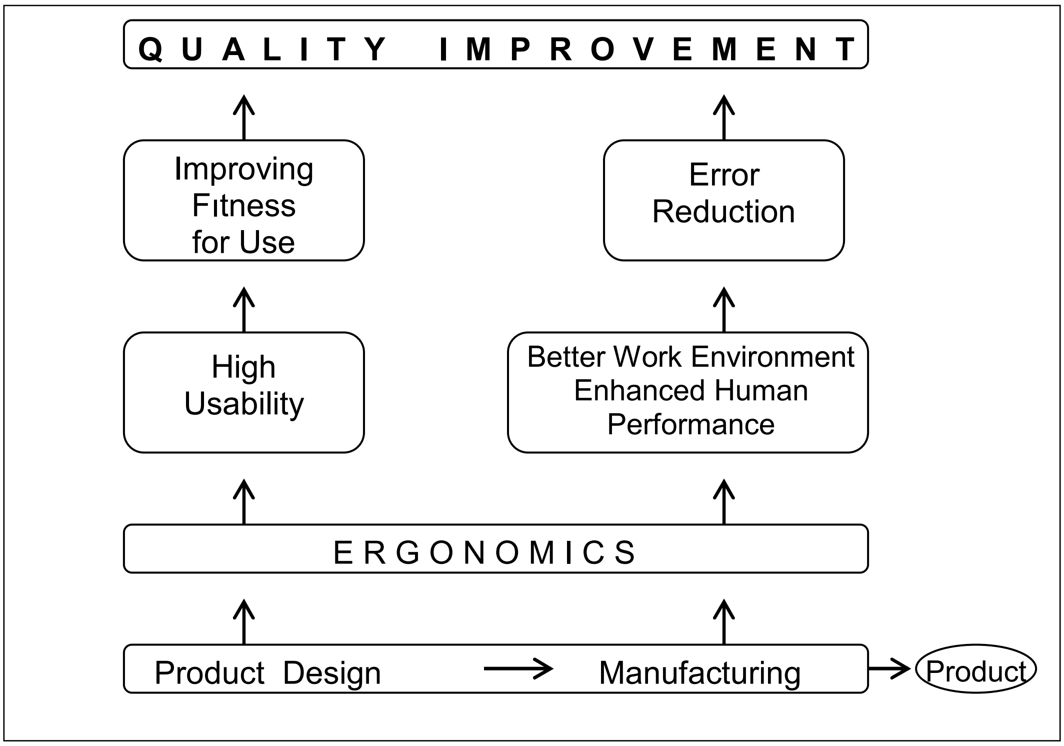

Figure III.3. Role of Ergonomics in Quality Improvement

III.2. DEVELOPMENT OF QUITE METHODOLOGY

Albeit researchers have followed certain paths to apply ergonomic analysis and interventions to improve quality, it is evident that, there is no well-defined methodology to employ ergonomics for quality improvement purposes. Of authors whose studies were surveyed, only Axelsson, (2000), has proposed a conceptual model (i.e. SIMPLE), for integration of quality and ergonomics. As mentioned in previous chapter, his model, though comprehensive and well-grounded, was conceptual and generic, rather than project level and particular for manufacturing context. Altough conceptual models provide insight into links, structures and oppurtunities relating to ergonomics and quality, it was observed that developing a clear-cut, project-level methodology to facilitate systematic progression of quality improvement effort and validation of this methodology via applications was necessary. As mentioned before, one of the main motivations for this dissertation study is to develop methodology which could fill in this gap for manufacturing context. This methodology should have been based on essential factors for success in implementation of quality and ergonomics improvements. Broad literature survey presented in previous chapters provided a substantial background to develop a methodology. This new methodology was titled; "Quality Improvement Through Ergonomics" and it is acronymed as "QUITE".

QUITE methodology is based on the theoretical study, assessments, explorations and synthesis of ;

- Quality improvement theory, applications and tools,
- Quality management applications,
- Ergonomics theory,
- Corporate ergonomics programs,
- Ergonomics intervention methods and tools,
- Relevant case studies in literature,
- Contemporary approaches in both quality and ergonomics concepts.

Development and core parts of QUITE methodology was depicted below.

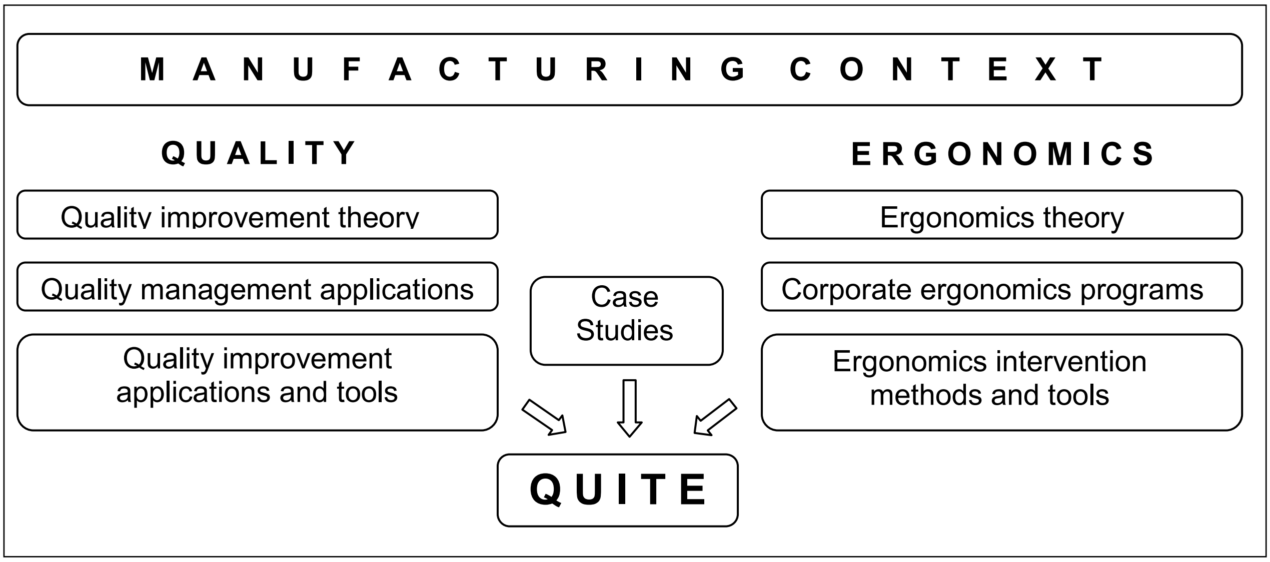

Figure III.4. Development of QUITE methodology

III.3. CONCEPTUAL FRAMEWORK OF QUITE METHODOLOGY

QUITE methodology adresses to all manufacturing environments in which three prerequisite conditions described in following are maintained;

- Human involvement in manufacturing process

In industrial terms, ergonomics is the science of fitting task and work environment to human. Hence, it is not possible to combine ergonomics and quality improvement where human is not involved in manufacturing process (MacLeod, 1995). Based on ergonomics and quality, QUITE could proposedly be employed in manufacturing environments where human involvement is significant.

- Quality system

There should be a manufacturing quality system where QUITE methodology was considered to be undertaken. The scale of the sytem may range from a quality specialist who follows the quality deficiency rates to corporate TQM system. This sytem should assure that quality is "*defined*" in company and inserted into goals and functioning of the corporation. Without quality data, it would not be possible neither to analyse the source and degree of quality problems nor to monitor the effect of QUITE project. Thus, quality data (e.g. deficiencies, rejected products) should be constantly monitored and should be available and up to date.

- Continuous improvement approach

QUITE methodology, similar to quality movements and ergonomic interventions it was based on, would require changes in work environment and processes. Thus, to accomplish quality improvement goals, QUITE should be applied with eagerness to learn, readiness and willingness to participate, enthusiasm toward novelties and decisiveness to accept change. Otherwise, any attempt for improvement would be likely to fail.

In the following, core elements of QUITE methodology were elaborated.

- Management commitment and involvement

It is not likely that organisational movements be accomplished without management support. One of the very fundamental parts in ergonomics project planning is to gain top management commitment (Drury, 1997, Hendrick, 2003, Karltun, 2004, Kohn and Friend, 1993, Noro, 1991). Ergonomics projects should be introcuded to management and benefits of the project should be expressed in economic terms with which managers are familiar (Smith, 2003). Commitment should include resource allocation, identification of authorities and responsibilities, permission to implement changes, involvement in progression of project and motivation of the participants.

Top management support should be visible, constant and in action, not solely verbal (Drury *et al*, 1999, Hendrick, 2003). Ergonomics projects or movements should be congruent with strategic goals rather than internal micro-level objectives (Drury *et al*, 1999). In this respect, managers are those who can direct the projects in concert with strategic goals of the companies.

Successful ergonomics programs usually begin with convincing and involving management. Form of management involvement should be determined and the participation of managers should be maintained along with the pace of project. Managers that can significantly affect the progress should be informed and consulted all along the project. Management representatives should participate in trainings and should be kept informed about project. Ergonomics generally addresses to engineers, designers, occupational safety and health specialists. Unlike quality, managers with different backgrounds would be unfamiliar with ergonomics knowledge and principles. Thus, giving a short ergonomics training might be useful for managers.

QUITE methodology is supposed to be easy to convey to management in that integration of ergonomics with quality reduces ergonomics concept to quality terms.

Gaining top management commitment is the first core element of QUITE methodology. Abovementioned principles should be taken into consideration throughout QUITE application. Training about interventions, quality improvement and case studies is a part of gaining management support. QUITE methodology should also be introduced to managers to have a common medium for communication and to set and evaluate objectives. Scope and limitations of the project should be specified in cooperation with managers.

- Communication

As posed by researchers and practitioners, communicating the progress of the corporate projects to affected parties is a key issue (Macleod, 1995, Hendrick, 2003). Macleod, (1995), emphasized that majority of ergonomics project failures stemmed from lack of effective communication. Communication should be effective and continuous. Progress of project should be reported to affected managers and employees in order to gain confidence and support for project.

Communication methods should be defined at the onset of QUITE application. Analysis results should be reported duly to affected parties. Period of reporting should be specified according to completion of sub-targets. Effective communication could make project results visible and keep QUITE project high on corporate agenda. Suitable communication medium should be selected. Active network or intranet systems can be employed to announce project ongoings.

Ideas gathered through participation (e.g. proposals of employees) should be responded at least to demonstrate that participation is valuable. Decision making should begin with minor affected managers. Proposals should be presented to and discussed with subordinate managers before being presented to top management. This approach would facilitate acceptance and implementation of changes at floor level. A proposal that is not likely to be supported by floor level personnel should not be communicated to top managers.

- Participation

Participation is a focal issue in both quality and ergonomics concepts (Feigenbaum, 1991, Wilson and Haines, 1997, Deming, 1986). Deming, (1986), emphasizes that, knowledge of members about company should be employed along with their physical capabilites. Ergonomic improvements by expert and limiting ergonomics interventions to micro level excluding integration with organisation is challanged by authors as participatory approach was incorporated into ergonomics since early 90's (Axelsson, 2000, Bagnara *et al*, 1996, Drury, 2000b, Eklund, 2000, Kivi and Mattila, 1991, Pipinich *et al*, 1993, Smith, 2003, Halpern and Dawson, 1997, Keyserling *et al*, 1991, Noro, 1991).

Nagamachi, (1995), defines participatory ergonomics as "workers' active involvement in implementing ergonomic knowledge and procedures in their workplace." He further points to requisites of participatory ergonomics and proposes that while upper level structure for participatory ergonomics should include managers, low levels should involve shop floor level people.

Relying solely on micro ergonomics efforts was expected to fail as ergonomics improvement approach if organizational issues were overlooked (Hendrick, 1991). According to Halpern and Dawson, (1997), participatory ergonomics provides a holistic approach to identify and eliminate risk factors and to dovetail ergonomics improvements in organisational structure. Participation movements (e.g. training sessions, committees) bring members from different organisational levels (e.g. managers, supervisors, engineers, baseline employees) together, which enhances company-wide communication. Improvements, when designed by participatory groups are more likely to be owned by people. Noro, (1991), propounded methods to persuade managers apply participatory ergonomics. While involvement of affected parties through participation is demanding, implementation of interventions could be quick in return. Employee participation is a part of employee empowerment, which was considered as a contribution to quality improvement (Adam and Foster, 2000).

Keyserling *et al*, (1991), suggest that workers, supervisors and ergonomics professionals are the basic members of any ergonomics job analysis team. They further suggested involvement of health personnel in ergonomic job analysis process. Participation of employees and line managers are strongly recommended in order to provide ownership of change process (Naderi and Baggerman, 1992, Hendrick, 2003, Chan *et al*, 2002, Noro, 1991). Participation leads not only to higher work performance but also higher job satisfaction for employees (Noro, 1991).

Chan *et al*, (2002), conducted a set of ergonomics interventions in sewing industry in order to alleviate adverse affect of MSD's. They propounded that key factor in enlisting worker acceptance was participation of employees and community organizations.

Vink *et al*, (1995), carried out participatory ergonomics project in a computer data entry workplace. They structured the project in step-wise manner and involved employees and managers in planning, analysis and selection of improvement alternatives. They concluded that more solutions for ergonomic problems were invented by employees. Acceptance of improvements was reported to be easier and more successful via participation. They found that drawback of participation was length of involving all parties in each step of the project.

Bagnara *et al*, (1996), applied participatory ergonomics in revamping of a hot strip mill. In the first phase of the study a working group which was formed by employees with different qualifications evaluated efficiency and effectiveness of existing work systems. After technological and organizational changes, some performance measures were adversely affected. Followingly, participative work system design was carried out via workshops. A more flexible production system was designed and principle of utilizing skills and experiments of the employees was adopted. In the end, reject rate of 1.42 % (i.e., after organizational changes) was reduced to 0.73 % through participative work design. Kuorinka and Patry, (1995) and Nagamachi, (1995), present numerous participatory success stories.

Employees participate in ergonomics projects or quality systems in various forms (e.g. quality circles, workplace design teams). To achieve objectives of participation, purpose, level (i.e., macro or micro), focus (i.e., organization or a single workstation), timeline (i.e., continuous or discreet), involvement approaches (i.e, direct or representative) and form (i.e. voluntary or obligatory) of participation should fit company structure (Wilson and Haines, 1997). Kuorinka and Patry, (1995), propounded that participatory tools should be simple to apply and to create common understanding of problems.

Due to its essential role in ergonomics improvement projects, participation is considered a core element for implementation of QUITE methodology. Participatory groups in existing quality systems such as quality circles can be employed for QUITE project. Ergonomics is a multi-disciplinary science involving numerous branches such as; engineering, medics, psychology and design. Literature on corporate ergonomics programs demonstrates benefits of this multi-disciplinarity in improvement projects (Butler, 2003, Hagg, 2003, Jones, 1997, Joseph, 2003, Smyth, 2003). Thus, this multi-disciplinary structure should be conserved for participation to QUITE project.

Noro, (1991), suggested that in order to ensure productivity of participation programs, problems should be scaled to small cases which could be solved by small teams. Down scaling problems can help people have the feeling that they can cope with and get over the problems. Outcomes of such cases would be concrete and complete which would exhort people for further cases. Participation plans should include communication medium and method. Kuorinka, (1997), suggested that learning process is the essence of participatory ergonomics. Ease in communication facilitates sharing new ideas and help employees to express their creativity (Karltun, 2004).

Computer based visualization is an emerging powerful tool for participation and communication. Blome *et al*, (2003), explored computer supported visualisation of ISO 9000 standarts in three small scaled companies. These companies had some problems in ISO 9000 implementation (e.g. little information flow, lack of regular updating of the system). The research was carried out by three design teams formed in each company. Company representatives in these teams conveyed their needs regarding visualisation of the system. The teams designed prototype software that was including graphics, hypertext and pictorial descriptions of standart elements (e.g., overview of production processes, work instructions, and sub-process flowcharts). Company personnel evaluated final prototypes of visualized systems. New systems were found to be easy to access, fast to understand and to use. As this case study implied, company networks or internet can be used to visualize flow of of QUITE project, to maintain communication among participatory groups and to collect ideas as practically as possible.

It was not deemed proper to mandate a participation form within QUITE methodology. The crucial point is to utilize the power of participation and to facilitate acceptance of required changes.

- Training

Ergonomics literature provides ample evidence about crucial role of training in achieving objectives of corporate projects (Pun *et al*, 2004, Sullivan and Corlett, 1998, Herbert *et al*, 2001, Halpern and Dawson, 1997, Keyserling *et al*, 1993). Training enables people identify ergonomics problems and enhances communication. Even basic trainings have proved to be useful in arising awareness to ergonomic problems in work place. According to Smith, (2003), training facilitates growing an ergonomics culture in organisatons and self resolution of ergonomics problems in manufacturing. Eklund, (2000), suggested that fewer problems occur in workplace if necessary ergonomics training is given to participants. It is not likely that people could identify ergnomics problems in their workplace without training. Number of reports about corporate ergonomics programs in manufacturing companies such as Volvo (Ulfsfalt *et al*, 2003) and Peugeot-Sochaux, (Moreau, 2003), supports that training is essential to maintain participation, to equip participants with necessary ergonomics knowledge, to build a common understanding towards ergonomics problems, and to develop sound measures against identified problems. Kuorinka and Patry, (1995), suggested that training is the core part of participatory ergonomics concept.

Training is an extension of participation and links participation to problem identification and solving in QUITE project. It was considered that training should be given to employees about ergonomics problems at the onset of intervention phase. Training should address to ergonomics problems identified in analysis phase. Training audience should include affected managers which would improve communication about ergonomics problems. It was observed that when equipped with knowledge, operators could come up with practical solution alternatives. Objectives and concept of QUITE project should be emphasized in training. Training should be in concert with requirements of manufacturing environment. Workflow should not be disturbed and content should fit education level of audience and be kept to-the-point. Training audience should be provided with written material such as manuals or course notes. Training could be incorporated into quality management activities, which would facilitate acceptance (Macleod, 1995). Scope and form of training should be determined in parallel with structure and work programs of the companies.

- Quality definition, goals and indicators

Quality practices should be based on corporate quality concept of an organization, which may differ across factors such as business area, management model, corporate culture and educational profile. Basically, having a well-defined concept of quality is important to identify and evaluate the levels of quality performance (Adam and Foster, 2000). Some practices maybe expected from employees for quality purposes, however, with different perceptions toward quality, expected and experienced quality practices are likely to lack harmony and to fail in results. Thus, for QUITE project, "*quality*" in the company should be well-defined. This definition will ease understanding towards and assessment of quality goals.

QUITE is a quality improvement oriented methodology. Thus, ergonomic analysis and interventions should follow identification of quality goals, analysis of quality performance and selection of quality critical tasks which have oppurtunities for improvement. Quality improvement focus in QUITE would bring multiple benefits. Performance in ergonomics projects can be evaluated by number of work related indicators such as; reduction in discomfort, absenteeism, and musculoskeletal disorders or increase in productivity and subjective job satisfaction. Following up ergonomics projects is demending in that they may last long or results may be too subjective or blurred to measure (e.g. reduced discomfort). Evaluation of project results by quality indicators would lead to more tangible interpretations.

Quality performance in manufacturing is measured using indicators. Depending on the manufacturing area and quality goals, indicators such as defect rate, percent defective products, percent reprocessed products should be used to measure changes in quality performance. In aforementioned case studies, Gonzalez *et al, (2003)*, used proportion of rejected and reprocessed parts per lot, Eklund, (1995), used deficiencies and remarks, and Lin *et al,* (2001), used number of defective cameras per week to measure the change in quality performance. Yeow and Sen, (2003), used cost of returned products along with defect percentage rate as quality indicator. It is imperative that selected indicators should allow analysis of quality performance against ergonomics improvements. These indicators should be measurable before/after ergonomic interventions. Given ergonomics adresses to human error, quality indicators should reflect operator-related quality problems. Quality problems stem form machinery or material, which do not relate with human involvement, would not yield accurate results. Furthermore, quality indicators should be traceable for lines or departments in which ergonomics interventions were implemented. Confounding effects of external factors should be excluded from computation of quality indicators. Corporate wide quality indicators might yield misleading information for interventions implemented in certain departments or lines.

- Ergonomics analysis tools and intervention methods

There exists variety of tools to conduct ergonomics analysis of factors such as; work load, postures, work environment. Ergonomics analysis tools in industrial context can be examined in three divisions (Li and Buckle, 1999a); Objective measurement methods, observational methods and subjective methods.

Breadth of literature on ergonomics research methodology revealed that, at least two types of ergonomics methods should be employed in order to supplement inadequacies of the other method (Li and Buckle, 1999a). As emphasized by Noro, (1991), ergonomics tools should be practical so that non-mastered people could understand and use them in real time work environments. While objective measurement methods (e.g., Motion analysis, Electromyography), yield direct results, tedious nature, high costs and requirement for special equipment and high command of ergonomics theories limit use of these methods to laboratory researches rather than practices in manufacturing environments.

Observational and subjective methods have proved to be highly applicable, and cost effective in manufacturing context. Observational methods such as RULA, (Mcatamney and Corlett, 1993, Massaccesi *et al*, 2003), Rapid Entire Body Assessement (REBA, Hignett and Mcatamney, 2000), OVACO Work Posture Analysis System (OWAS, Karhu *et al*, 1977), were used in literature to quantify and evaluate work posture and ergonomics risks in various manufacturing environments. Given that awkward postures is a common ergonomics problem which indicate ergonomics problems in workplace, focal point of these methods is observation and quantification of work postures via video analysis (Keyserling *et al*, 1991). Majority of researchers conduct video analysis of work process and environment (Lin *et al,* 2001, Yeow and Sen, 2003, Gonzalez *et al,* 2003). Pen-paper based observation techniques have been recommended for static jobs (Li and Buckle, 1999a). Disadvantage of observational methods is lack of employee participation and perception toward ergonomics risks.

Subjective analysis methods such as checklists and questionnaires have been commonly uitilized in ergonomics research due to their high predictive validity, low cost and ease of data collection (Annett, 2002, Björksten *et al*, 1999). Li and Buckle, (1999a), presented a broad compilation of subjective tools and methods. While objective measurements reveal the true values of variables, subjective measurements show how ergonomic problems are perceived by individuals. Subjective methods help to estimate consequences of alternative interventions. Annett, (2002), propounded that subjective rating tools should be selected or developed in order that they fit particular goals of research.

Checklists are practical and reliable tools for analysis of work environment from numerous ergonomics standpoints such as prevalence of MSDs, postural discomfort or mental workload (Annett, 2002, Keyserling *et al*, 1993). For validity of the research it is of high importance to select or structure correct type of checklist which would yield reliable outcomes. Brodie and Wells, (1997), compared utilities of three checklists and proposed that such analysis tools should be used with caution.

Questionnaires are most widespread tools for subjective ergonomics analysis. Variety of questionnaires is employed in ergonomics literature such as; Cornell questionnaire (Cornell University Ergonomics Web, 1999) or Dutch work and health questionnaire (Hilderbrandt *et al*, 2001). Main advantages of questionnaires are; employee involvement, ease of application and low cost.

Another ergonomics risk assessment tool is Quick Exposure Check, (QEC), which combines observation with subjective reporting in that it includes worker assessment along with observer assessment (Li and Buckle, 1999b and 1998, David *et al*, 2005). It addresses to variety of interacting risk factors such as; awkward postures, exposure duration, vibration and stress. Its validity and usability aspects were improved in recent years and updated version of QEC was published by a further development report in 2005 (David *et al*, 2005).

QUITE methodology addresses to all manufacturing environments in which human is involved. Thus, suitable analysis tools should be selected in harmony with characteristics of manufacturing context and employee profile. Tasks that offer improvement oppurtunity (e.g bottlenecks, complex tasks with high error frequency and high discomfort) should be identified before selection of tools. Ergonomic analysis tools should be selected depending upon; task in question, number and educational background of employees and applicability and ease of data collection. Tools should be applied before/after ergonomics intervention and besides quality indicators, changes in ergonomics problems should be monitored using these tools. Solely tools that were used in application will be elaborated in following chapters.

Conceptual framework of QUITE methodology is depicted in the diagram below.

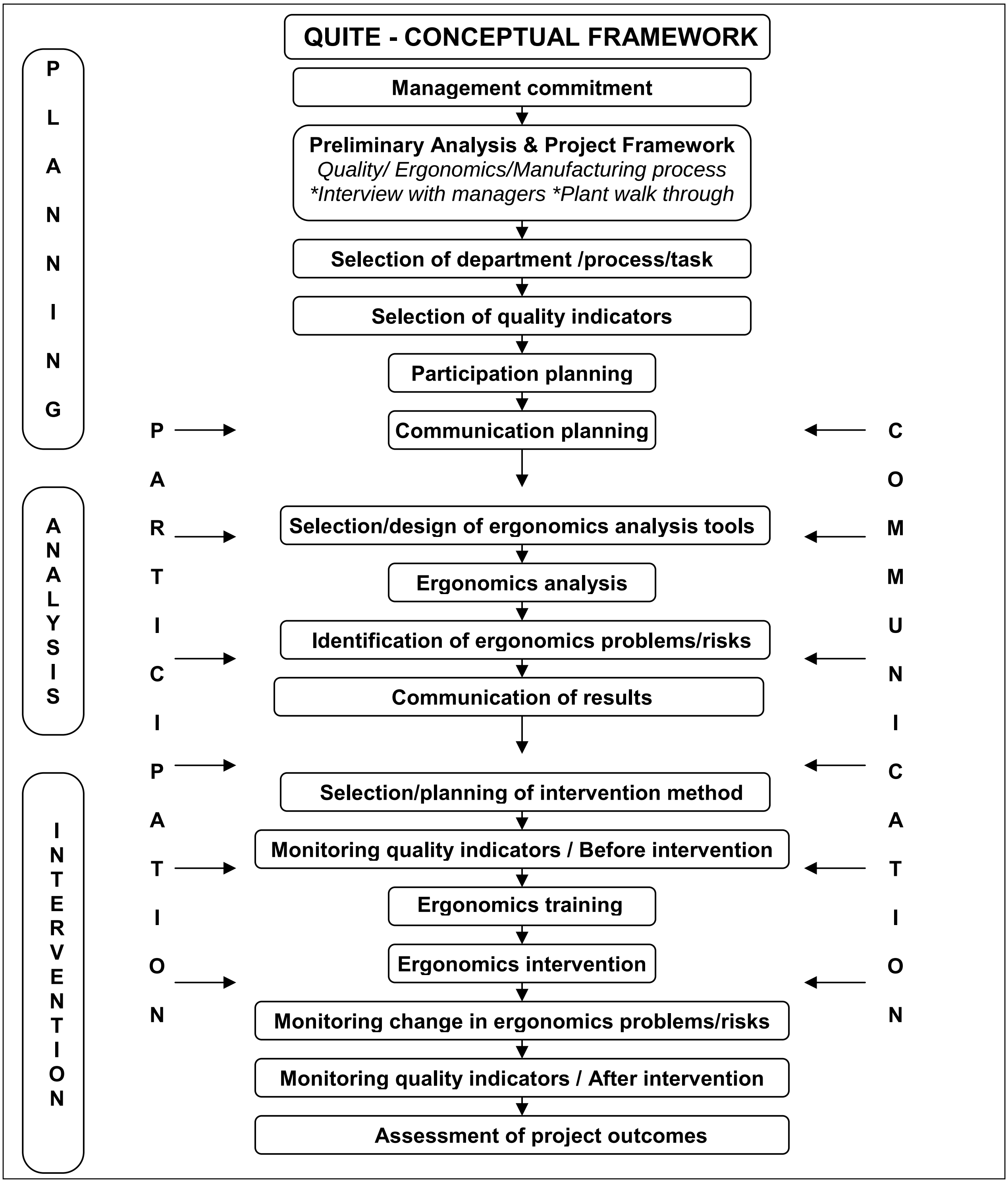

Figure III.5. Conceptual Framework of QUITE Methodology

CHAPTER IV

APPLICATION OF QUITE METHODOLOGY IN TALU TEXTILE

IV.1. COMPANY PROFILE AND MANUFACTURING CONTEXT

Talu Textile with its two plants at Istanbul and Adapazari is one of the big scale apparel manufacturing companies of Turkish textile industry and a member of Taha Group. QUITE methodology was applied in Istanbul plant, in which more than 300 personnell were employed and full apparel manufacturing including; clothe cuttting, clothe classification, visual inspection of clothe, machine sewing, visual inspection, ironning and packaging processes was carried out.

Talu Textile was found to meet three prerequisite condition of QUITE methodology. All manufacturing processes in the company weightly involved human-labour intensive tasks which introduced substantial need for employment of ergonomics and satisfied first prerequisite condition (i.e. human involvement in manufacturing process). Human error was major source of quality deficiencies that resulted in high quality costs incurred by products rejected by either company quality system or customers. Thus, main determinant of corporate quality performance was degree of human error. In this respect, human error reduction through ergonomic interventions, inherent objective of QUITE methodology, was an attractive quality improvement alternative.

Major customers of Talu Textile were globally famous foreign companies which mandated utmost quality performance. Particularly cost of quality problems met abroad was likely to result in great financial losses. For example operations for a deficient batch rejected by a foreign customer, incurred storage and handling costs with foreign currency and amounted to crucial losses in monetary terms. Hence, quality performance was a highest priority issue in Talu Textile. Company had a quality department which was responsible for improving manufacturing quality performance and maintaining corporate quality system. Quality manager, who was originally an industrial engineer, subordinated directly to Chief Executive Officer, (CEO), of company. Operator related quality deficiencies (e.g., sewing errors) formed a considerable portion of total quality deficiencies. Therefore, reduction of operator related quality problems was one of the corporate quality improvement objectives. At the onset of study, quality system was being revised for renewal of ISO 9001:2000 certification. QUITE project was observed to be an opportunity to address ergonomics and quality issues in parallel with these revision activities. Presence of a quality system and high priority of quality in company satisfied second prerequisite condition for QUITE project (i.e. quality system).

Continuous improvement was one of the core management principles in Talu Textile. CEO of company, originally an industrial engineer, was known for his eagerness about improvement oriented activities personally, which encouraged middle managers to maintain a dynamic manufacturing environement. For example; floor supervisor of sewing department had invented an apparatus which was mounted on sewing machines and served to eliminate five sub-tasks. Middle managers of Talu textile, majority of them being engineers, were successful professionals with strong educational backgrounds. This improvement-oriented atmosphere satisfied third prerequisite condition of QUITE methodology (i.e. continuous improvement approach) and facilitated initiation of QUITE project.

IV.2. PROJECT OUTLINE

QUITE project was undertaken between March–November 2005. Outline of QUITE project was demonstrated in figure below.

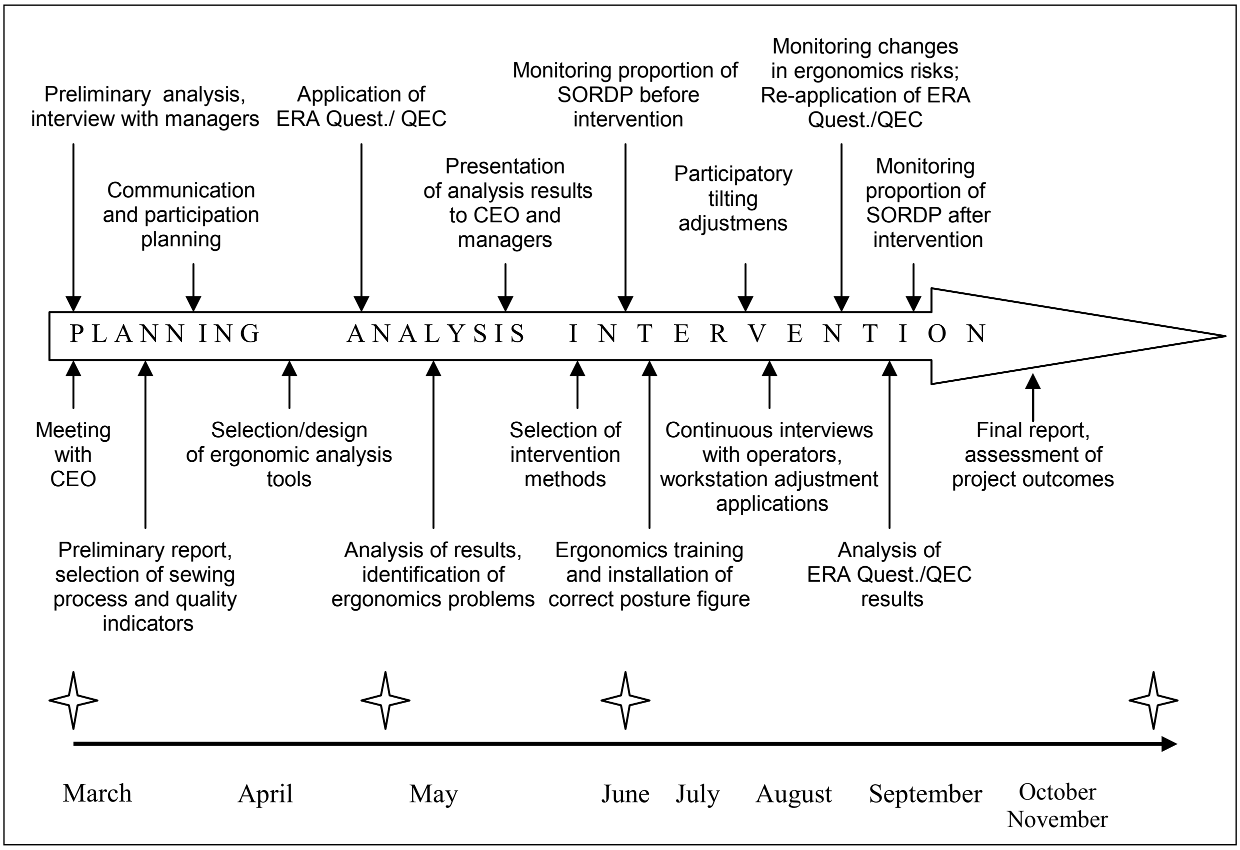

Figure IV.1. Outline of QUITE project

In the following application of QUITE project was elaborated.

IV.3 PLANNING PHASE

IV.3.1. Management commitment

Initially, concept, objectives, relevant case studies and methodology of QUITE project was presented to CEO of Talu Textile in a personal meeting. An introductory report was presented in order to state the project in a formal manner. Potential benefits such as quality improvement, ergonomics analysis, ergonomics improvements such as reduction in ergonomics risks and free ergonomics training were emphasized. It was clarified that QUITE project was totally academic and solely publication right was requested in return. Owing to his industrial engineering background, it was not needed to introduce basic ergonomics issues and CEO of Talu Textile accepted to start project within quality program of company.

Quality manager of the company, who was an industrial engineer as well, was assigned to QUITE project as the contact person. Following the meeting with CEO of Talu Textile, QUITE project was presented to quality manager. It was clarified that quality system of company had been being revised and re-structured. QUITE project was perceived as an oppurtunity to identify ergonomics problems in the company. Quality manager was selected as "champion" that would facilitate project planning and implementation of necessary changes (Mcleod, 1995).

After this second meeting, third meeting was held with CEO of Talu Textile and quality manager together. It was agreed upon to commence QUITE project. Author was given full plant access and authorization to carry out all necessary steps for the project. CEO of Talu Textile encouraged author to assess current system freely and to identify ergonomic problems.

IV.3.2. Preliminary analysis and project framework

A plant walk-through was conducted as the first step of preliminary analysis. Departments and manufacturing environments were visited by the author. Project was briefly introduced in an informal manner to middle managers and department supervisors who would potentially be affected. Company personnel interviewed were; human resources manager, industrial planning manager, chief production manager, supervisors of sewing, quality control and cutting departments.

Apparently owing to improvement-oriented approach of top management, responses of mid-managers were quite encouraging. In further steps, it was better observed that informal communication with affected parties in early initiation phase facilitated identification of suitable tasks and implementation of interventions within QUITE project. Interviews were carried out to identify; corporate targets that QUITE project would serve, suitable processes for project, oppurtunities and limitations for potential improvements. Applicability of alternative ergonomics tools were discussed in order to foresee potential drawbacks.

Academic structure of the project, sound theoretical preparation and presentation of case studies in literature were persuasive factors in interviews.

Involvement of managers early in project planning instead of acting upon direct orders of CEO was the most important factor in earning the initial trust and support of company personnell. Managers and supervisors felt secure that no step would be taken out of their control in progression of project. These interviews became key of preventing resistance to project.

Company employed two doctors working in shifts. Available doctor was visited and interwieved about project. It was clarified that neither patient data nor statistics on prevalent MSDs was being logged. Lack of medical data entailed that analysis of MSD prevalence and severity be included in analysis of ergonomics risks and problems.

Outline of manufacturing process in Talu Textile was depicted below.

Figure IV.2. Manufacturing Flow in Talu Textile

IV.3.3. Selection of manufacturing process

All manufacturing processes in Talu Textile were labor intensive and involved opportunities for ergonomics intervention and quality improvements. A decision matrix was structured with quality and production planning managers to select suitable process for QUITE project. Evaluation via decision matrix showed that labour intensive machine sewing process had most significant impact on corporate quality performance that can be enhanced via ergonomics. Reduction of operator-related quality deficiencies offered a substantial quality improvement opportunity. Furthermore sewing process was considered suitable for practical low cost ergonomics interventions. It was agreed upon by mid-managers and CEO of Talu textile to commence project in machine sewing process.

There were 8 lines in each of which 15-25 employees were assigned. For statistical concerns (i.e. having to conduct surveys with at least 30 participants), first and second lines, with 30-35 available employees were selected as pilot lines for project. It was planned that practices which would be deemed useful for corporate quality performance would be extended to other lines and Adapazari plant as necessary. Decision matrix used for process selection was presented below.

Table IV.1. Decision Matrix for Selection of Suitable Manufacturing Process

Process⟶ **↓Criteria**	Clothe Cutting	Clothe Classification	Machine Sewing	Visual Inspection	Ironning	Packaging
1.Improvement potential	1	2	3	2	2	1
2.Impact on quality	3	2	3	3	2	2
3.Oppurtunity for low cost intervention	1	3	3	2	2	1
4.Adequacy for academic research	1	2	3	3	2	1
5.Effect of ergonomics on quality performance	2	2	3	2	2	1
6.Contribution to human well-being	1	2	3	2	3	1
Total	**9**	**13**	**<u>18</u>**	**14**	**13**	**7**

Low:1, Moderate :2,High:3

IV. 3.4. Selection of quality indicators

Quality indicators were selected in cooperation with quality manager of Talu Textile. Quality performance of machine sewing process was monitored at two phases:

- In-process quality control

Quality department personnel were assigned for visual inspection of semi-products (i.e. apparels) during sewing process. Employees that committed errors and caused product defects were identified and those with high error rates were marked. In-process defect rate was the first valid quality indicator in sewing process.

- Visual inspection

Sewing process was linked to visual inspection process. All products were exposed to visual quality control at the end of sewing line operation. Defective products were classified into; “Reprocess” and “2nd Quality” groups. Products that had operator related defects were classified in “Reprocess” group.

Quality department was assigned to issue weekly quality reports which included defective, reprocessed and 2nd quality product figures on batch and line basis. Quality data included number and percentage of defective products per batch and detailed summary of defect types. Hence it was possible to track defects stemming from operator-related errors in sewing department. Occurrence of defects due to immaterial components of manufacturing such as raw material or machines was possible. Since ergonomics interventions within QUITE project addressed to sewing operation and aimed to reduce operator errors, proportion of “Sewing-Operator-Related Defective Products” (SORDP) per batch was deemed suitable to measure quality improvement. It was agreed upon with manufacturing planning manager and quality manager that quality performance of project lines be monitored via percent SORDP before / after ergonomics interventions.

IV.3.5. Participation Planning

Participation was planned to be managed at supervisor level initially. Floor supervisor of sewing department and supervisors of two project lines formed basic participation group. It was planned to expand participation to operators in further steps of project. Production planning manager and quality manager were included in participation group as well. Given the observed fact that a formal participation such as a nominated QUITE project committee would be a drawback, participatory group was preferred to be kept informal yet functional. Members of participatory group were given authority to make decisions regarding QUITE project by CEO of Talu Textile, which facilitated implementation to a large extent. Weekly meetings were planned to be held about progression of QUITE project. Available members would participate in weekly planned steps as necessary. Advancements and reports were delivered to participation group via e-mail. Other personnel, such as visual quality inspectors or maintenance team were involved in project as necessary through communication with core participation group. Thus, functionality was given higher priority than formality which kept participation process dynamic and effective.

All advancements were proposed to and discussed with participatory group (i.e. pretest of ERA questionnaire, administration of ERA questionnaire and QEC) prior to bringing the issues to CEO of Talu Textile. This approach ensured that feasible action alternatives which were to be proposed to CEO of Talu Textile would already be agreed upon with functional managers and supervisors.

IV.3.6. Communication Planning

As emphasized by Macleod, (1995), effective communication was the key factor in success of corporate ergonomics projects. In this stage, CEO of Talu Textile was consulted about communication and reporting requirements. He was notified that progress of QUITE project would be presented by written reports in further steps and status of the project would constantly be reported. Quality manager, production planning manager and supervisor of sewing department were identified as middle managers to whom planning and progress of project would be communicated in accordance to their responsibility areas. While monitoring of quality indicators would be undertaken with quality manager, ergonomics analysis and interventions at manufacturing lines were planned to be carried out with production planning manager and floor supervisor of sewing department.

Constant informal interviews were planned to be an inherent part of the project progression. Project steps were planned to be discussed and agreed upon with effected middle managers prior to presenting to CEO of Talu Textile. Operators in project lines were planned to be included in interviewes. Progression of QUITE project, such as results of ergonomics analysis was planned to be communicated not only to managers but also participant operators in order to involve them in project and effectively convey project objectives.

Communication planning made clear the correct way of action in company with regard to managerial hierarchy, revealed conscious about managerial issues and built confidence in Talu Textile managers that advancement of project would be under controlled conditions.

IV.4. ANALYSIS PHASE

IV.4.1. Analysis objectives

Main objectives in analysis phase were;

- To identify ergonomics risks which may alleviate human well-being and quality performance,
- To pinpoint intervention areas that would lead to quality improvement,
- To get familiar with characteristics of work force; which was important to enhance communication, to facilitate planning and implementation of ergonomics interventions.

IV.4.2. Selection and design of ergonomics analysis tools

IV.4.2.1 Ergonomics analysis tools

Ergonomics analysis tools used in industrial context can be examined in three divisions (Li and Buckle, 1999a);

- Objective measurement methods (e.g., Motion analysis, Electromyography)
- Observational methods (e.g. RULA, OWAS, QEC)
- Subjective methods (e.g. checklists, questionnaires)

Breadth of literature on ergonomics research methodology revealed that, at least two types of ergonomics methods should be employed in order to complement inadequacies of the other method (Li and Buckle, 1999a). In natural manufacturing environment, subjective and observational methods proved to be highly applicable and to have potential to yield sound results. Pen-paper based observation techniques have been recommended for static jobs (Li and Buckle, 1999a), which pointed to the potential benefits of observational methods in garment industry.

Within QUITE project, a questionnaire to evaluate ergonomics risks was developed as a subjective analysis tool and QEC, an observational method for practical assessment of ergonomics risks was selected to complement questionnaire. Questionnaire was custom tailored for characteristics of machine sewing task. In the following, ergonomic characteristics of machine sewing task investigated, development of ergonomics analysis questioannaire and QEC were elaborated.

IV.4.2.2. Ergonomic characteristics of machine sewing task

Machine sewing is a core task in textile industry. It involves multitude of musculoskeletal (MS) risks that bring severe occupational health concerns for a vast employee population globally (Pun *et al*, 2004).

Figure IV.3. Machine Sewing Process in Talu Textile

There is ample evidence about prevalence of MS disorders and discomfort in machine sewing task, which supports the intensity of MS risks and need for ergonomics intervention. Blader *et al*, (1991), proposed that MS disorders among sewing operators have been prevalent since ‘70s. Of common MS disorders, upper extremity injuries comprise the main portion and substantially contribute to medical costs in apparel industry (Kelly and Ortiz, 1992). MS disorders were reported to prevail in neck, shoulder and back (Halpern and Dawson, 1997, Li *et al*, 1995, Delleman and Dul, 2002, Bezjak and Knez, 1995, Kelly and Ortiz, 1992). Vezina *et al,* (1992), analyzed sewing task and found that body area with highest reported MS discomfort was shoulders. Perez and Anda, (1993), investigated MS discomfort among male sewing operators in shoemaking industry via posture targeting and a questionnaire. They reported that 47.5 % of participants had persistent MS discomfort and 18.2 % of participants cited low back pain.

Blader *et al,* (1991), conducted a questionnaire about prevalence of neck and shoulder complaints among machine sewing operators in Sweden. They found that prevalence rate for neck and shoulder complaint symptoms in 12 months and previous seven days were 75 % and 51 % respectively.

Analysis of MS risks is essential in order to develop sound occupational safety and health measures and to plan effective ergonomics interventions in industrial environments. Body of research revealed that common MS risks in machine sewing task were; awkward postures (Delleman and Dul, 2002, Kelly and Ortiz, 1992), prolonged static work (Bezjak and Knez, 1995, Chan *et al*, 2002), high work pace, repetitiveness, excessive pinch grips (Pun *et al*, 2004, Herbert *et al*., 2001, Halpern and Dawson, 1997, Li *et al*, 1995, Chan *et al*, 2002), and forward flexion (Quintana, 1997). Vezina *et al*, (1992), proposed that components of physical workload in sewing machine operation were force, repetition, posture and inadequate recovery time. Visual demand of the sewing task, workstation and seating problems were suggested to be major causes of awkward postures (Kelly and Ortiz, 1992, Li *et al*, 1995). Chan *et al*, (2002), elaborated sewing job cycle at micro level operations.

Although use of observational analysis methods is widespread in ergonomics literature, few studies exemplify observational risk assessment applications in machine sewing task. Bezjak and Knez, (1995), applied OWAS (Karhu *et al*, 1977) to evaluate reduction of physical loading on sewing operators before and after improvement of workstation design. Quintana, (1997), investigated MS risk factors in machine sewing task with back injury focus, using Continuous Safety Sampling Methodology (CSSM) which is based upon work sampling concept. He identified bending forward and to the sides in excessive degrees (i.e. 10^o and 20^o) as a risk factor and detected that back injury risk was increasing toward the end of the week since work pace was getting higher to meet quota. In this respect, application of QEC in machine sewing task would contribute to originality of present dissertation.

Typical sit-sew workstations with different types of sewing machines (e.g. single–needle straight-stitch, single-needle overlock machines), were used in company. Majority of case studies in literature adresses to single-needle straight stitch machine sewing workstation. In essence, generic ergonomics principles apply to all types of sewing machines with subtle differences such as varying degree of wrist-deviation exposure. However, all types of machines were extensively used in manufacturing process, significantly affecting quality performance and posing similar ergonomics risks. Therefore, in order to thoroughly integrate ergonomics interventions into natural manufacturing context, all sewing operators in project lines were involved in training and intervention process regardless of machine type.

IV.4.2.3. Ergonomics Risk Analysis (ERA) questionnaire

Subjective self-report is a widely used screening method in ergonomics research. Questionnaires are commonly used before/after analysis in ergonomics interventions to measure subjective changes in occupational health issues (Chan *et al*, 2002, Aborg *et al*, 1998). Spielholz *et al*, (2001), provided ample knowledge and compared methods to measure MS risk factors at upper extremities. Self-reports posit psychophysical characteristics in that respondents reveal their sensations to stimuli (e.g. risk factors). Thus, questionnaires can be accepted as psychophysical metrics (Spielholz *et al*, 2001). Subjective reporting of physical discomfort (e.g. pain) has been a valid method for detecting MS problems which stem from ergonomic problems. Björksten *et al*, (1999), provided evidence that subjective reportings of pain by Swedish female industrial workers were in congruence with clinical findings. They suggested that frequent application of such questionnaires can be helpful to follow-up discomfort symptoms, to identify worker groups of individuals susceptible to occupational ailments and to measure workplace hazards.

Albeit variety of ergonomics risk evaluation questionnaires in literature applies to manufacturing environments, subjective analysis tools were recommended to fit particular requirements of research goals (Annett, 2002). Hence, it was considered more convenient to develop a customized questionnaire which address to objectives and content of present study, profile of participant group and specifications of sewing task.

In these respects, Ergonomics Risk Analysis (ERA) questionnaire was developed to identify and quantify degree of ergonomics risks and MS discomfort, particularly for QUITE project, based upon a vast literature survey (Björksten *et al*, 1999, Brodie and Wells, 1997, Charlton, 1996, Drury, 1999, Herbert *et al*, 2001, Keyserling *et al*, 1993, Li and Buckle, 1999a, Spielholz *et al*, 2001, Sullivan and Corlett, 1998, Yeow and Sen, 2003).

Numerous analysis methods and tools widely used in ergonomics context such as; RULA (Massaccesi *et al*, 2003, Mcatamney and Corlett, 1993), REBA (Hignett and Mcatamney, 2000), OWAS (Karhu *et al*, 1977), Cornell MS Discomfort Questionnaire (Cornell University Ergonomics Web, 2001), Dutch MS Questionnaire (Hilderbrandt *et al*, 2001), Nordic Questionnaire, (Barros and Alexandre, 2003, Dickinson *et al*, 1992, Kuorinka *et al*, 1987), Job Design Questionnaire (Medsker and Campion, 1997), Job Content Questionnaire (Ostry *et al*, 2001), Aberg loading/causes survey (Sullivan and Corlett, 1998) and body part discomfort survey (Sullivan and Corlett, 1998), were elaborated prior to structuring ERA questionnaire. Specific project requirements induced from preliminary analysis, interviews, nature of manufacturing context and work design were taken into account.

Methodology of Charlton, (1996), was followed to design ERA questionnaire:

* Questionnaire type was selected.

* Response scale and descriptor set was structured.

* Questions were worded. Double barrel questions, leading/loaded questions, emotionality were avoided. Questions were kept brief and relevant to the extent possible.

* Elements of questionnaire were assembled. Items to be rated were selected and put in an order.

* Questionnaire was reviewed and pretested by managers, supervisors and three operators from other lines for clarity of content, relevance of items and understandability of wording.

ERA questionnaire addressed to ergonomics risk factors below;

- Severity of problems caused by work environment (Part A),
- Severity of problems caused by work station elements (Part B),
- Frequency of exposure to physical ergonomics risks (Part C),
- Severity of mental discomfort caused by work characteristics (Part D),
- Musculoskeletal (MS) discomfort (Part E),
- Verbal data about causes of human errors (At the end of each part).

While part C addressed to work related physical ergonomics risks such as awkward postures, part E addressed to MS discomfort across body areas which was a potential effect of physical ergonomics risks.

ERA questionnaire was structured such that severity, frequency and prevalence of ergonomics problems could be evaluated on four-point scale. While frequency of exposure was evaluated in part C, other parts included severity ratings. Qualitative data gathered through verbal questions supplemented quantitative data and provided insight to quality problems. At the end of each part, participants were asked to explain the discomfort/problem they report and if there was any other pertinent factor that causes ergonomics risk in workplace. They were further asked to list the alternative improvements that can be carried out to solve problems they reported.

Common drawbacks of self-reports; variability in psychologic factors, subject literacy, difficulty in comprehension and interpretation of questions (Dickinson *et al*, 1992) were addressed via conducting ERA questionnaire by interviewer and keeping its structure balanced between concise and comprehensive.

Majority of generic subjective analysis tools, listed above were designed for audience at a certain education level. However, work force in Talu Textile was substantially low educated. Thus, ERA questionnaire was prepared to fit low education level and poor reading habits of respondent group.

Four-point scale was used in order to simplify decision-making of participants. Anchors were worded as understandable as possible; Turkish synonyms of No, (1), Sligthly, (2), Moderately, (3), Severely, (4), being used for severity, Never, (1), Sometimes, (2), Frequently, (3), Always, (4), being used for frequency. In MS discomfort part, questions were coupled with a body diagram to facilitate visualization of body parts.

IV.4.2.4 Quick Exposure Check (QEC)

Quick Exposure Check, (QEC), is a MS risk assessment method which was developed by health and safety practitioners with a participatory approach (Li and Buckle, 1999a, 1999b and 1998, David *et al*, 2005). Objective of developing QEC was to provide occupational safety and health practitioners with a scientifically valid, user friendly and reliable method to carry out MS risk assessment (David *et a*l, 2005). QEC combines observation with subjective reporting in that it includes worker assessment along with observer assessment. It addresses to variety of interacting MS risk factors such as; awkward postures, exposure duration, vibration and stress. The method is based upon scoring existing risk factors such that higher the score, higher the risk. Risk levels for various ranges of scores were proposed. Validity and usability aspects were improved in recent years and updated version of QEC was published by a further development report in 2005 (David *et al*, 2005).

Main features of QEC were suggested to be ease of pen-and-paper application, short time requirement to complete assessment, employment of both observation and subjective reporting through involvement of workers, applicability with a short training and usability of scoring system (David *et al*, 2005). Due to its abovementioned properties, QEC was considered highly applicable to machine sewing task which involves low postural variability. A sample of QEC question form and scoring table was presented in Appendix-A.

IV.4.3. Ergonomics Analysis

IV.4.3.1 Participants

Sewing operators assigned in two project lines (n=36, 14 males, 22 females, 21 from Line1, 15 from Line 2), participated in ERA questionnaire on voluntary basis. Their mean age was 28.72 years and mean tenure at job was 38.83 months. Proportion of elementary, secondary and high school graduates were 63.9 %, 30.6 %, 5.6 % respectively. Of 36 participants, 21 operators (58 %), were from Line 1 and 15 operators (42 %) were from Line 2. Videotaping for QEC was performed with 31 operators. Five operators were not available due to casual reasons (i.e., four of them were assigned to a task other than sewing, other one was off early afternoon).

IV.4.3.2. Application of ERA questionnaire and QEC

ERA questionnaire and QEC were applied in April 2005. Employees were not informed about QUITE project until application of questionnaire, in order to prevent any uncontrolled effect. Before conducting ERA questionnaire and prior to work, a meeting with project lines was held. Employees were given brief information about objectives and concept of the study. It was emphasized that their occupational health and well-being would be focal point of analysis. Effort to analyze occupational health issues was appreciated by operators and they participated in a supportive manner. Subsequently, ERA questionnaire and "Worker's Assessment" part of QEC was started.

"Worker's Assessment" part included questions to be answered by worker in an interactive manner. This part was translated into Turkish by authors and was pretested by production manager and floor supervisors from clarity and content standpoints. Pen-paper QEC forms were used in the study (David *et al*, 2005). Operators were seated close to each other at machine sewing lines. Given their low education level, it was considered possible that they could have been influenced by responses of precedent participants. In order to avoid influence between operators and not to disturb manufacturing process, ERA questionnaire and "Worker's Assessment" part of QEC was planned to be conducted in interview settings in a separate room near machine sewing department. Participants were sent to survey room successively under control of floor supervisors so that work flow was not disturbed by their absence.

Initially, each participant was given instructions regarding to survey and privacy of responses. Participant name was neither asked nor recorded in order to assure anonymity, which was deemed essential to gain confidence of participants. A coding system was devised to match survey responses and QEC scores of each operator. Each participant was given a "participant number" label at the beginning of survey. This number was taken down on the ERA questionnaire and QEC forms. Operators were instructed to keep the label and to give it back during videotaping for QEC. The reason set forth for label exchange was to assure that all survey participants were also videotaped. Participants were asked to fill ERA questionnaire form and they were given necessary help in understanding and responding to items. "Worker's Assessment" part of QEC was completed interactively. Completion of each questionnaire and "Worker's Assessment" part of QEC took about 15 minutes.

After all participants completed ERA questionnaire and "Worker's Assessment" parts of QEC, work postures were videotaped for "Observer's Assessment" part of QEC. Since QEC required observation of worst case postures, afternoon period, when awkward postures would weightly prevail due to increasing fatique and stress, was preferred for videotaping. Each operator was videotaped from angles that enabled accurate observation of required body areas. Samsung SCL 860 8mm. camera was used for videotaping. "Participant number" label was received back from each operator and screened by camera. Videotaping of each employee took about 5-10 minutes. Owing to low postural variability in machine sewing task, videotaping for 5-10 minutes sufficed to observe representative work postures. "Observer's Assessment" part of QEC was completed aftermath via analysis of videotapes, which made repetetive observations possible. ERA questionnaire and QEC form of each participant was matched using participant number screened on video recordings. Thus, ergonomics analysis was completed successfully without compromising anonymity. Data extracted from ERA questionnaire was assessed in combination with QEC results.

IV.4.4. Identification of ergonomics problems/risks

IV.4.4.1. Results of ERA questionnaire

Results of parts A, B, C and D of ERA questionnaire were presented in Table IV.2 below.

According to results of part A, participants pointed to air quality, climate (i.e. excessive heat in workplace) and noise as prevalent problems in severity rank order. Lighting in sewing facility was considered adequate, which was supported also in verbal answers. Most intensive adverse factor, which reportedly alleviated air quality was dust. Dust is known to be typical environmental problem in textile industry work. High dust concentration not only affects air quality adversely but also hinders installation of air condition system, which contributes to environmental heat stress.

In part B, appreciably low mean severity ratings showed that employees were content with workstation components. As reported by managers and supported by employees, Talu Textile has offered a considerably fitting workstation. Majority of participants with previous job experience emphasized that adjustable sewing chairs were rarely used in textile industry and Talu Textile was among very few companies offering these chairs to sewing operators. It was observed that one of the strengths of Talu Textile was providing adjustable workstations and a relatively fitting work environment to employees, which was ensued by high job satisfaction.

Results of part C showed that, in line with literature, bending upper body, neck and wrists were frequent work postures involving ergonomics risks, with mean frequencies; 2,833, 2,694, and 2,917 respectively. Visual discomfort is a prevalent cause of awkward postures, particularly bending neck and upper body. Frequency of exposure to visual discomfort was found to be lower than anticipated.

Table IV.2. Results of ERA Questionnaire, Parts A, B, C and D

A.Do you feel discomfort by…	
Anchors: No(1) Slightly(2) Moderately(3) Severely (4)	Mean (Std.dev.)
A1.Noise	2,000 (0,894)
A2. Lighting	1,361 (0,592)
A3.Climate	2,361 (1,246)
A4.Air quality	2,778 (0,989)
B.Do you feel discomfort in using..	
Anchors: No(1) Slightly(2) Moderately(3) Severely (4)	Mean (Std.dev.)
B1.Sewing machine	1,277 (0,566)
B2.Table	1,083 (0,280)
B3.Chair	1,111 (0,318)
B4.Pedal	1,166 (0,447)
B5.Hand tools	1,277 (0,454)
C.During work, do you…	
Anchors: No(1) Sometimes(2) Frequently(3) Always (4)	Mean (Std.dev.)
C1.Bend your upper body?	2,833 (1,082)
C2.Bend your neck?	2,694 (1,238)
C3.Feel visual discomfort?	1,583 (0,770)
C4.Feel obstructed by engine etc. underneath the table?	1,083 (0,280)
C5. Have to reach extensively?	1,556 (0,652)
C6. Bend your wrists?	2,917 (1,204)
C7. Lean your arms on sharp edges?	1,500 (0,971)
C8.Find your rest breaks insufficient?	1,361 (0,762)
D. Answer the following questions.	
Anchors: No(1) Slightly(2) Moderately(3) Severely (4)	Mean (Std.dev.)
D1.Does your work require mental effort?	2,333 (0,956)
D2.Does your work involve error risk?	2,667 (0,894)
D3.Is your job monotonous?	2,000 (1,042)

It was considered that participants were unaware of cause-and-effect relation between visual discomfort and awkward postures. Participants indicated that visual discomfort occurred particularly while sewing heavily dark or heavily bright colors using strings in a similar tone. In parallel to adequacy of lighting system, visual discomfort was not proposed to be a major problem in work environment. These awkward seating postures of bending upper extremities formed primary targets of ergonomics intervention.

In part D, majority of participants reported that sewing task involved mental effort and error risk, with mean ratings 2.333 and 2.667 respectively. Error risk was partly attributed to inadequacy of information given prior to work. Participants propounded that errors stemmed from distraction and lack of operators' concentration on work. They further suggested that error could be reduced if operators could be careful enough during work. It was considered that adverse work environment factors (e.g. excessive heat stress and noise), fatique and awkard postures mentioned in part C (i.e. bending upper body, neck and wrists), could contribute to distraction and lack of concentration which leaded to human errors. Job monotony was not propounded to be intensive. Due to high unemployment countrywide, operators do not have the chance to select jobs that totally meet their expectations. Therefore, having a job is considered good enough in socio-economic terms which eliminate complaints about factors such as monotony.

Results of part E of ERA questionnaire were presented below.

Table IV.3. Results of ERA Questionnaire, Part E

E. Do you feel discomfort (ache, pain, numbness, tingling etc.) in ...				
Anchors: No(1) Slightly(2) Moderately(3) Severely (4)				
	NO(%)	YES(%)	MEAN	(Std.dev.)
Neck	13 (36,1)	23 (63,9)	2,028	(0,971)
Right shoulder	21 (58,3)	15 (41,7)	1,694	(0,980)
Left shoulder	24 (66,7)	12 (33,3)	1,583	(0,967)
Upper back	12 (33,3)	24 (66,7)	2,306	(1,167)
Low back	11 (30,6)	25 (69,4)	2,222	(1,045)
Right arm	26 (72,2)	10 (27,8)	1,417	(0,770)
Left arm	26 (72,2)	10 (27,8)	1,389	(0,728)
Right wrist	30 (83,3)	6 (16,7)	1,278	(0,741)
Left wrist	33 (91,7)	3 (8,3)	1,166	(0,561)
Right hand	31 (86,1)	5 (13,9)	1,222	(0,637)
Left hand	34 (94,4)	2 (5,6)	1,111	(0,523)
Right leg	21 (58,3)	15 (41,7)	1,556	(0,735)
Left leg	17 (47,2)	19 (52,8)	1,889	(0,979)
Right foot	28 (77,8)	8 (22,2)	1,389	(0,803)
Left foot	25 (69,4)	11 (30,6)	1,611	(1,022)

Results of Part E, which addressed to MS discomfort, were evaluated in prevalence and severity dimensions. Discomfort was described by Turkish synonyms of ache, pain, numbness, tingling (Dickinson *et al*, 1992) and further explanations were provided to participants as necessary. Prevalence of MS discomfort across anatomic sites was evaluated by counting “No” responses as an indication of absence of MS discomfort, while counting all other responses, which involved discomfort to a certain degree, as an indication of presence of MS discomfort. Severity of MS discomfort was evaluated by mean rating values. Results showed that, MS discomfort prevalence for neck, upper and lower back parts were 63,9 %, 66,7 % and 69,4 % respectively, which pointed to high MS risks for upper extremities. MS Discomfort prevalence at legs was also considerable. Correlations between discomfort severity ratings across body parts were investigated using MINITAB software. Significant Pearson correlations (i.e., $p \leq 0.05$) higher than 0,4 were accepted reasonable. Pearson correlation coefficients were presented in Table- IV.4. below.

Table IV.4. Significant Correlations between MS Discomfort Severity across Body Parts

SIGNIFICANT CORRELATIONS BETWEEN MS DISCOMFORT SEVERITY													
	Nec.	R.sh	L.sh.	U.ba.	L.ba.	R.ar.	L.ar.	R.wr.	R.ha.	L..ha.	R.le.	L.le.	R.fo.
R.sh	**,40**												
	,016												
L.sh	**,408**	**,555**											
	,013	**,000**											
U.ba.	,295	**,359**	**,369**										
	,081	**,032**	**,027**										
L.ba.	,304	,319	**,490**	**,482,**									
	,072	,058	**,002**	**003**									
R.ar.	**,596**	,287	,163	,140	,166								
	,000	,090	,342	,414	,334								
L.ar.	,308,	-,22	**,358**	,125	,184	,161,							
	068	,179	**,032**	,467	,284	347							
R.wr	**,426**	,002	,286	,196	,102	-,06	**,377**						
	,010	,990	,091	,251	,552	,735	**,024**						
R.ha.	,313	**,478**	,154	,060	,010	,272	-,007	,108					
	,063	**,003**	,368	,729	,956	,109	,968	,533					
L..ha.	**,388**	-,043	**,433**	,224	,215	-,047	**,634**	**,582**	,010				
	,019	,802	**,008**	,189	,208	,784	**,000**	**,000**	,956				
L.le.	-,03	-,09	,221	,256	**,388**	-,08	**,423**	,280	-,09	,304	**,406**		
	,877	,578	,195	,132	**,019**	,608	**,010**	,098	,575	,071	**,014**		
R.fo.	-,05	-,03	-,12	,053	,098	,146	-,02	,005	-,12	-,04	**,641**	,129	
	,768	,879	,499	,761	,568	,394	,900	,975	,494	,827	**0,00**	,453	
L.fo.	0,01	-,26	,120	,246	**,351**	-,006	,324	,222	-,21	**,351**	**,** 29	**,726**	,259
	,948	,119	,484	,148	**,036**	,972	,054	,193	,209	**,036**	,080	**0,00**	,127

Discomfort at neck was found to correlate strongly with other upper extremities; shoulders, upper and lower back, arms and right wrist. Discomfort at right/left shoulders and upper/lower back were considerably correlated. These results implied that, MS discomfort prevailed at upper extremities due to adverse affects of awkward posture on MS structure. Dicomfort ratings at legs and feet are also correlated, presumably due to awkward posture of lower extremities.

Pareto analysis, one of the principal quality improvement tools (Juran and Gryna, 1993), was applied on MS discomfort prevalence across body parts.

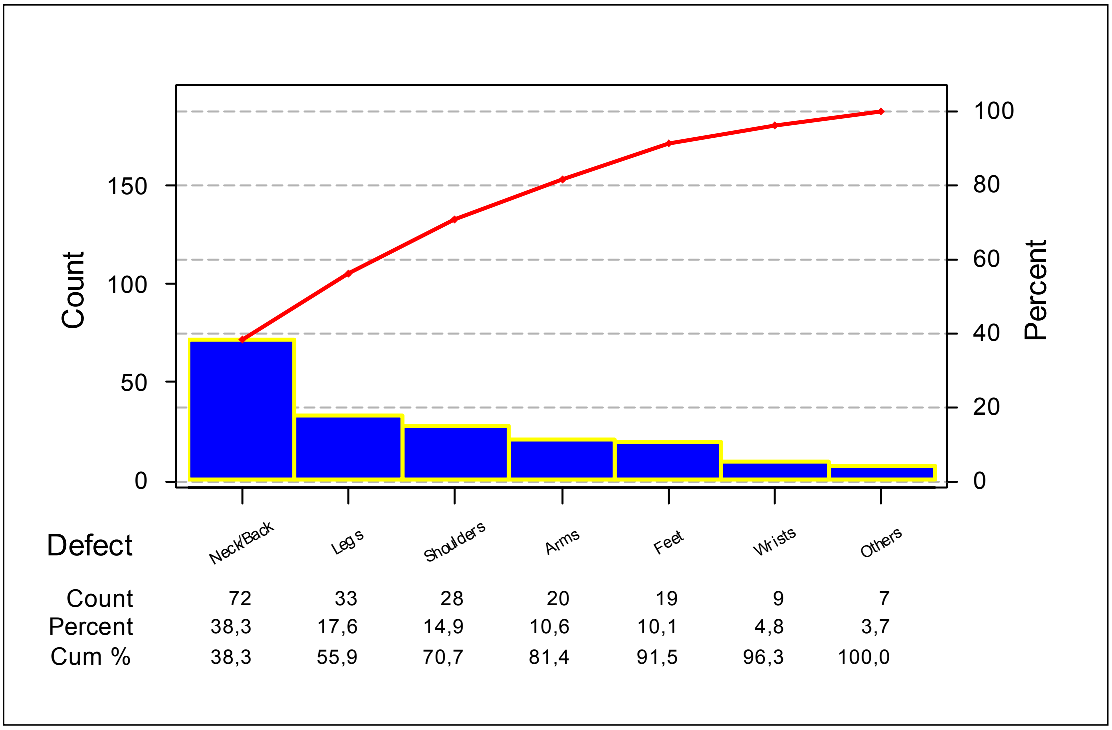

Figure IV.4. Pareto Diagram of Reported MS Discomfort

It was found that, 70.7 % of total reported MS discomfort was in neck/back, legs and shoulders. Pareto chart provided persuasive evidence that interventions should primarily address to risks for neck and back. MS discomfort was known to have adverse affects on manufacturing performance in that operators suffering pain in body parts would be prone to committing errors. Operator error rates were expected to diminish through reduction of ergonomics risk factors.

Abovementioned results implied that awkward postures formed the core ergonomics problem in sewing task and underlying factors that force operators to bend forward would be potential intervention areas for interventions within QUITE project. Lack of medical records was compensated to an extent by application of part E of ERA questionnaire. These findings were congruent with results of previous research in that highest MS risks exist in upper extremities (Bezjak and Knez, 1995, Delleman and Dul, 2002, Halpern and Dawson, 1997, Kelly and Ortiz, 1992, Li *et al*, 1995). It was considered that lack of ergonomics consciousness and knowledge about correct work posture and useful workstation adjustments contributed to occurence of awkward postures.

IV.4.4.2 Results of QEC

Mean QEC scores and risk exposure levels were presented in table below.

Table IV.5. QEC Scores and Risk Exposure Levels

QEC Body Areas and Risk Factors	Proposed Exposure levels (David *et al*, 2005)				Mean Score (Std.D.)	Exposure Level
Back(Static)	Very high	High	Moderate	Low	26,258	High
	29-40	23-29	16-22	8-15	(1,770)	
Shoulder/Arm	Very high	High	Moderate	Low	33,355	High
	41-56	31-40	21-30	10-20	(1,817)	
Wrist/Hand	Very high	High	Moderate	Low	25,355	Moderate
	41-46	31-40	21-30	10-20	(1,496)	
Neck	Very high	High	Moderate	Low	17,419	Very high
	16-18	12-14	8-10	4 - 6	(0,923)	
Driving	Very high	High	Moderate	Low	1,000	Low
	-	9	4	1	(1,000)	
Workpace	Very high	High	Moderate	Low	4,323	Moderate
	-	9	4	1	(2,358)	
Vibration	Very high	High	Moderate	Low	1,000	Low
	-	9	4	1	(1,000)	
Stres	Very high	High	Moderate	Low	7,484	Moderate
	16	9	4	1	(4,760)	

QEC scores and observations indicated remarkable MS risks in machine sewing task; awkward work postures, prolonged static work, workstation design problems and high visual demand. None of the operators drove vehicles and sewing machines were not introducing vibration. Hence, two of the MS risk factors in QEC; driving and vibration were omitted from analysis as they did not apply to sewing task in question.

Video analysis revealed that all operators were flexing their neck and back forward. In congruence with literature, it was observed that these awkward postures stemmed from latter MS risks (Li *et al*, 1995). Official break schedule in company required 2-2.5 hours of continuous static work, which intensified adverse affect of other risk factors and have made awkward postures hard-to-change habits. Visual demand; need to view fine details of clothe and stitches at sewing operation point forced operators to bend forward. Level of exposure to MS risk factors was “Very High” for neck and “High” for back and shoulder/arm.

Risk level for wrist/hand was “Moderate”. Particularly operators using single-needle straight-stitch machines were observed to maintain neutral wrist during sewing operation, which reduced overall risk level for wrists/hands. In addition, similar motion patterns were not very frequent (i.e. less than 20 times per minute), which mitigated adverse affect of wrist deviation or bending.

Exposure level for work pace and stress was found to be “Moderate”. However, high mean score of 7,484 indicated notable risk of stress. High work load, problems pertaining work environment (e.g. excessive heat, low air quality), psychological problems and adverse social relations were reported by participants to be sources of stress at work.

Correlations between QEC scores across body areas and risk factors were investigated. Solely neck and shoulder/arm scores were found to be significantly correlated (p=0.024), with Pearson correlation coefficient of 0.405. It was observed that as operators bent their upper body and neck forward, height of their hands were increasing to chest or shoulder level, which contributed to shoulder/arm scores. Task duration was common interacting risk factor which contributed to both neck and shoulder/arm scores equally. Thus it could be suggested that there existed a positive relationship between postural risk of neck and shoulder/arms.

It was further sought to reveal if discomfort prevalence at upper extremities and MS risk exposure levels identified via QEC were in agreement. It was presumed that operators, who were highly exposed to MS risks for upper body areas, would suffer from discomfort at upper extremities and legs. Due to aforementioned contribution of incorrect foot pedal positioning on adoption of awkward work postures prevalence of discomfort at legs was included in this analysis. Thus, MS risk exposure levels at back, neck and shoulder/arms of participant groups who reported discomfort for upper extremities and legs were investigated. Number of participant group who were taped and reported discomfort for relevant body parts and distribution of MS risk exposure levels over those body areas were presented in table below.

Table IV.6. Agreement between MS Discomfort Prevalence and QEC-MS Risk Exposure Levels

	QEC BODY AREAS AND MS RISK EXPOSURE LEVELS – N(%)					
Operators with discomfort in...	**BACK**			**NECK**	**SHOULDER/ARM**	
	V H	*H*	*M*	*V H*	*H*	*M*
Neck	1 (5)	18 (90)	1 (5)	20(100)	17 (85)	3 (15)
Upper back	3 13.64)	17 (77.27)	2 (9.09)	22(100)	18(81.82)	4 (18.18)
Low back	3 13.64)	17 (77.27)	2 (9.09)	22(100)	19 (86.37)	3 (13.64)
Right shoulder	3(21.43)	11 (78.57)		14(100)	13 (92.85)	1 (7.15)
Left shoulder	2 16,67)	10 (83,33)		12(100)	10 (83.33)	2 (16.67)
Right leg	3 (25)	7 (58.33)	2 (16.67)	12(100)	12 (100)	
Left leg	3 (17.65)	14 (82.35)		17(100)	15 (88.24)	2 (11.76)

VH: Very high, H: High, M: Moderate.

Agreement results demonstrated that, majority of participants who had discomfort at upper extremities and legs were exposed to “High” and “Very High” MS risks for back, neck and shoulder/arm. Given that MS discomfort could stem from or intensified by MS risks, results implied that QEC was substantially accurate in identifying effective MS risk exposure levels. It could be expected that, MS discomfort would alleviate as MS risk exposure levels could be reduced through measures such as ergonomics interventions (e.g. tilting machines, ergonomics training). Neck scores of 16 – 18 correspond to “Very High” risk exposure level in QEC scoring system (David *et al*, 2005). Thus, risk exposure at neck was “Very High” for all participants who reported discomfort at upper extremities, neck and legs. QEC score for neck was dependent on three factors; neck posture, visual demand and work duration. It was observed that all participants were maintaining non-neutral neck postures; 29.03 % of them occasionally, 70.97 % of them continuously bending their neck forward. Latter two factors were included in “Worker’s Assessment” part. Visual demand was assessed to be high as a characteristic of sewing task and a certain need to see fine details during sewing operation was reported. Work duration was more than 4 hours for all participants. Hence, neck assessment scores were 16 or 18 dependent on the occasional/continuous bending of neck.

IV.4.4.3. Assessment of ergonomics risks and problems

It was found via ERA questionnaire and QEC that machine sewing task in Talu Textile involved certain ergonomics risks; static and awkward work postures stemming from workstation settings, lack of training, lack of ergonomics knowledge and visual demand (i.e. forward bending of neck and torso looking at operation point, stitches and fabric), repetitive movements of arms, wrists and hands. Since mostly outfit wears were produced, fabrics were easy to handle without slipping. Work pace which is not controlled by employees, long work hours and overtime, discomfort caused by environmental factors prevail in work place.

Abovementioned results implied that awkward postures formed the core ergonomics problem in sewing task and underlying factors that force operators to bend forward would be potential intervention areas for interventions within QUITE project. Lack of medical records was compensated to an extent by application of part E of ERA questionnaire. These findings were congruent with results of previous research in that highest MS risks exist in upper extremities (Bezjak and Knez, 1995, Delleman and Dul, 2002, Halpern and Dawson, 1997, Kelly and Ortiz, 1992, Li *et al*, 1995). It was considered that lack of ergonomics consciousness and knowledge about correct work posture and useful workstation adjustments contributed to occurence of awkward postures.

Investigated through ERA questionnaire, MS discomfort at upper extremities; neck, shoulders, upper and lower back were found to prevail substantially, which supported previous literature (Bezjak and Knez, 1995, Blader *et al*, 1991, Delleman anf Dul, 2002, Halpern and Dawson, 1997, Li *et al*, 1995, Perez and Anda, 1993, Vezina *et al*, 1992). In addition to upper extremities, MS discomfort at legs was noticeable. Along with long static work, incorrect location of foot pedal (i.e. too close to operator), was supposed to cause awkward postures and discomfort at legs. Further analysis of agreement between MS discomfort prevalence and QEC risk exposure revealed that majority of participants who reported discomfort at legs were exposed to “High” or “Very High” MS risks at back, neck and shoulder/arm. These results implied that awkward work posture could cause discomfort not only at upper extremities but also at legs.

According to QEC results, MS risk exposure level was “Very High” for neck, “High” for back and shoulder/arm and “Moderate” for wrist/arm. Observations and assessments indicated that influential MS risks at machine sewing task were; long duration of static work (i.e. work schedule mandated nearly 2.5 hours of continuous work and about 10 hours of work daily), awkward work postures (i.e., forward flexion of upper body, neck and head, wrist deviation in some tasks), incorrect workstation settings (e.g. incorrect location of foot pedal and task height), and high visual demand. These findings supported previous body of research (Bezjak and Knez, 1995; Chan *et al*, 2002; Delleman and Dul, 2002; Quintana, 1997; Vezina *et al*, 1992).

Identified MS risk factors interacted to certain degrees. For example; as distance between operator and sewing machine increased due to location of foot pedal too close to front end, visual demand was intensified, which resulted in forward flexion of back and neck. Official breaks were given at 10.30-10.50 A.M. and 17.30-17.50 P.M., which causes 2-2.5 hours of continuous work. It could be suggested that maintaining nearly 2.5 hours of continuous work and about 10 hours of work daily in these conditions contributed to adoption of awkward postures as habitual manners. Work cycle and work load (i.e. number of pieces sewn per day) varied along the day according to quota. Moreover, rotation did not alleviate exposure since when rotated to another machine workload did not decrease. Elimination of these risk factors by ergonomics interventions was deemed crucial to enhance manufacturing performance. Microbreaks were possible when employees wait for pieces in workflow. These natural micro-breaks provide oppurtunities for breaking continuous workflow and to relieve constrained muscles. This point was emphasized during training.

Practices showed that QEC is highly applicable and effective in assessment of MS risks at machine sewing task. It can be suggested that effectiveness and usability ends proposed by David *et al*, (2005) and Li and Buckle (1998), were achieved. Agreement between discomfort prevalence and identified QEC risk exposure levels was substantially high, which supported effectiveness and accuracy of QEC in assessment of MS risks at sewing task. As mentioned before, MS risks identified via QEC were also consistent with those propounded in literature. It is clear that changes in MS risks after ergonomics interventions can be quantified, assessed and monitored using QEC. Question and scoring forms were simple to follow and complete, which substantiated the success of usability efforts (David *et al*, 2005). Training materials sufficed to provide insight for QEC method (David *et al*, 2005).

In many respects, QEC proved to be well-grounded, useful and practical. Employment of multiple analysis methods (e.g. subjective methods, observational techniques or direct measurement) in a complementary manner was recommended for ergonomics research (Li and Buckle, 1999a). QEC included assessment of both observer, who is a practitioner or expert by definition and worker, who performs the task in question. Thus, combination of observation and subjective reporting made a thorough assessment of MS risks and ergonomics risks possible. Involvement of workers not only contributed to assessment process but also facilitated worker acceptance and participation, which were crucial in research of the kind (Noro, 1991).

IV.4.4.4 Cause-and-Effect diagram

Cause-and-Effect diagram, which is widely known as Ishikawa or Fishbone diagram is one of the basic quality improvement tools. Juran and Gryna, (1993) and Wadsworth *et al*, (2002), presented various examples of Cause-and –Effect diagrams. It is is used to depict potential causes that result in a certain effect, generally an undesired one such as a quality defect. Given the fundamental approach of QUITE is integration of ergonomics with quality concept, a Cause-and-Effect diagram was built to demonstrate causal relationship between ergonomics risks/problems that adversely effect quality performance and sewing-operator-related deficiencies (SORD) as an undesired result of these risks/problems.

Ergonomics risks that cause SORD in machine sewing tasks were identified based upon results of ERA questionnaire and QEC analysis, interviews with operators and contributions of participation group. Ergonomics factors that lead to SORD were grouped into five divisions; physical factors, lack of knowledge, work methods, environmental factors and psychosocial factors. Cause-and-Effect diagram was helpful not only as an analysis tool but also a common vehicle for illustration of ergonomics issues in familiar structure of quality concept. This diagram served to pinpoint ergonomics problems that could be addressed with low cost interventions.

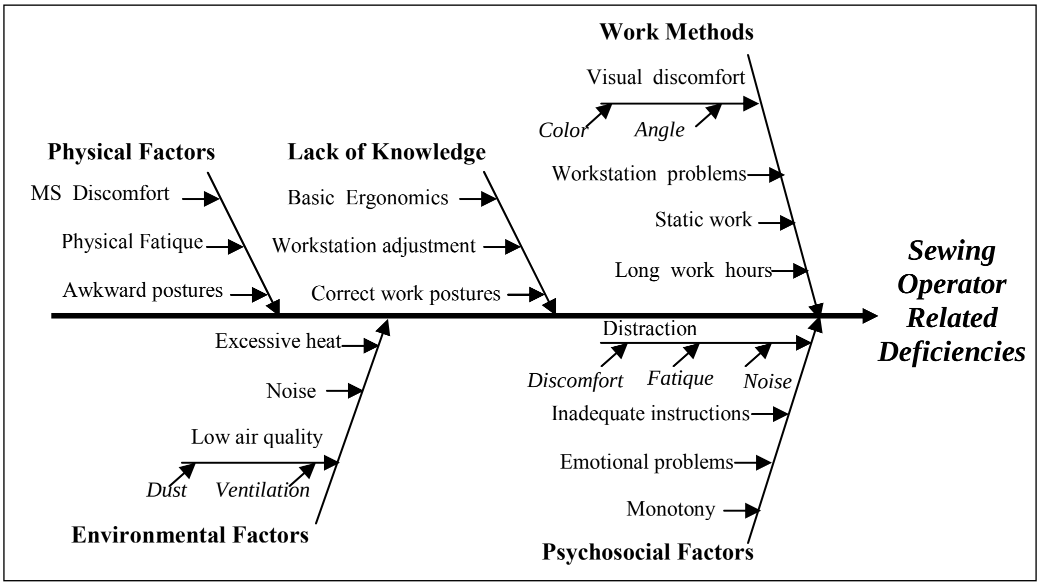

Figure IV.5. Cause-and Effect Diagram of Ergonomics Risks/Problems and Deficiencies

IV.4.5. Communication of results

Results of ERA questionnaire and QEC and assessments were presented to participation group and CEO of Talu Textile in an analysis report within a week. It was observed that presentation of analysis results in a timely manner created a positive impression on managers toward project. As emphasized by Macleod, (1995), effective communication has become the key issue in maintaining management support to QUITE project. Prior presentation of results to participation group before CEO of Talu Textile enhanced confidence of group members towards author and progress of project. Variety of potential improvements was proposed in analysis report in order to exchange ideas for further steps. These proposed intervention alternatives were elaborated in following sections. It was observed that presentation of results to all affected managers was well appreciated in company. Most considered that project was worth the efforts to analyze ergonomics problems and to improve quality.

IV.5. INTERVENTION PHASE

IV.5.1. Selection and planning of intervention methods

Analysis results and Cause-and –Effect diagram showed that, main ergonomics problems were related to; physical ergonomics problems, lack of knowledge, work methods, environmental factors and psychosocial factors. Solution to environmental problems entailed costly interventions such as installation of air condition system. Principal intervention strategy was to prefer no-cost and low cost improvements given that cost-prohibitive alternatives could have been rejected. Aligned with approach of management, low-cost interventions were given priority. Alternative improvements were included in presentation of analysis results and were discussed with participation group members from usefulness and feasibility standpoints. Initial planning of feasible improvement alternatives such as training and tilting machines was done within these discussions. Agreed upon intervention opportunities, potential gains and action plans of feasible interventions were presented to CEO of Talu Textile.

Analysis results demonstrated that basic ergonomics efforts that address workplace betterments could enhance manufacturing performance. Selected improvements were planned to be implemented gradually. In the following, planning, implementation and outcomes of ergonomics interventions were elaborated.

IV.5.2. Monitoring quality indicators before intervention

Proportion of "Sewing-Operator-Related Defective Products" (SORDP) per batch was the selected quality indicator. Prior to ergonomics interventions, proportion of SORDP per batch was analysed in retrospect to monitor quality performance. Determined analysis course of past data was 10 weeks. First intervention, ergonomics training was scheduled in early June, thus, past data extended to 10 weeks prior to June.

Summary of quality performance indicators and mean SORDP per batch during prior course was tabulated below.

Table IV.7. Summary of Quality Data before Ergonomics Intervention

QUALITY DATA (March-May 2005)				
Lines	N of batches	Total N of Products	Total Number of SORDP	Pro. SORDP
Line 1	39	18275	1630	% 8.9
Line 2	44	30198	1768	% 5.9
Total	83	48473	3398	% 7

Table IV.8. Mean Proportion of SORDP per Batch before Ergonomics Intervention

MEAN SORDP per batch (March-May 2005)			
Lines	N of batches	Mean	Std. Dev.
Line 1	39	0,0794	,064
Line 2	44	0,0606	,058

Quality data was planned to be monitored after interventions would be completed and comparison was to be performed over quality data of 10 weeks following ergonomics interventions.

IV.5.3. Ergonomics Training

It is suggested that ergonomics training is imperative to address lack of ergonomics knowledge, to streamline ergonomics risk identification and improvement efforts within participatory ergonomics approach (Sullivan and Corlett, 1998). In congruence with literature, ergonomics training was incorporated into QUITE project as an essential part not only to give operators a conscious about ergonomics problems but also to enhance participation (Herbert *et al*, 2001, Sullivan and Corlett, 1998). Authors have provided examples of ergonomics training applications. Pun *et al*, (2004), gave two-session ergonomics training for garment workers in California region. They examplified how to organize and apply ergonomics training to increase awareness to ergonomic problems in workplace. Herbert *et al*, (2001), installed and evaluated the impact of adjustable chairs in sewing lines. Prior to installation they trained operators about MS risks and how to use new chairs. They achieved significant reduction in reported pain and exposure to awkward postures.

Training was deemed crucial for success of planned interventions. Of the benefits expected from QUITE project, free ergonomics training was considered most valuable by CEO of Talu Textile and managers. Training was inserted into training schedule of corporate quality management program of Talu Textile.

Administration of training was planned in detail with participation group. Operators, floor supervisors of two project lines and participatory group (n=40) participated in training. Training was structured not only as a course but also as a workshop in which ergonomics practices and methods for self-adjustment of sewing workstation were discussed. In addition to equipping operators with basic and practical ergonomics knowledge, another important objective was to make operators familiar with planned interventions to facilitate acceptance and participation. Contents of training included necessary ergonomics knowledge and specific information regarding QUITE project; results of ERA questionnaire and QEC, physical ergonomics risk factors in sewing task, how to maintain a healthy work posture, how to adjust workstation and alternative interventions agreed upon by managers beforehand (e.g. tilting adjustment). Course content was simplified in order to allow low-educated operators follow the training without difficulty. Course content partly included information and material obtained from similar training programs given by Occupational Safety and Health Administration (OSHA, Official web site, 2003), which enhanced academical validity of training.

Training was held in 1 hour sessions with project lines in three groups during work. A meeting room with satisfactory conditions and computerized visual facilities was used for training. It was provided that participants did not have to allocate their free time for training purposes. Training began with assessments of ERA questionnaire and QEC results, particularly about discomfort rates and identified MS risks. Relationship between ergonomics problems (e.g. awkward postures) and adverse effects (e.g. poor quality performance), potential direct and indirect gains of correct work methods (e.g. enhanced occupational health and higher quality) was explained.

Subsequently participants were informed about concept of QUITE project; effect of ergonomics practices on quality performance and project objectives. Occupational health and high corporate quality were emphasized as potential outcomes of ergonomics efforts. Relevant case studies about quality improvement through ergonomics (Gonzalez *et al*, 2003) were presented to substantiate the potential of QUITE project. Correct work methods and ergonomics risk factors at sewing task (e.g. neutral sitting posture versus flexion of neck, back and wrist deviation, obstructions to correct seating at workstations, effect of visual discomfort on seating habits), correct workstation layout (e.g. correct versus incorrect position of foot pedal and task height) were presented with illustrations and examples. Given the utmost variability in body dimensions of workforce and rotation requirements, self-adjustment was considered more reasonable and applicable than employing classical ergonomics approach of taking antropometric measures and adjusting workstations to certain dimensions. Correct work posture model was demonstrated and methods for self adjustment and how to benefit from adjustability of workstation elements were introduced. Importance of interrupting static postures was emphasized. Operators were encouraged to take measures to mitigate static nature of sewing task such as taking micro breaks during occasional work flow. Applicability of alternative workplace improvements such as tilting adjustment were discussed with operators.

Participants were delivered an illustrated “Correct work methods for sewing operators” manual, which included basic ergonomics practices and correct work methods particular for machine sewing task. Manual was designed in line with technical comunication principles with a focused content, using short, familiar expressions without ambiguities, enriched with figures where necessary (Conrads, 1987, Gleason and Wackerman, 1984, Hartley, 1981). Manual was printed in pocket size in order that operators could practically carry and review it in workplace. It was targeted to reinforce positive immediate effects of ergonomics training and to attain long term behavioral change.

Interaction with participants and outcomes of training were satisfactory. Feedback about analysis results helped to gain operators’ support for QUITE project in that they felt as a significant part of project and quantitative results such as MS discomfort prevalence figures were effective in getting them focus on ergonomics risks and problems. They earned primary awareness about MS risks via communication of analysis results, which facilitated generating ideas as to elimination of ergonomics risks and product deficiencies. This interactive approach and giving participants an oppurtunity to express themselves increased their self-confidence and support toward project while facilitating acceptance of prospective interventions. Delivering the manual as a reference material enhanced operators’ concern about project. As was the case with studies presented by Kuorinka and Patry, (1995), training proved to be helpful in involving operators into QUITE project and following ergonomics interventions.

IV.5.4. Ergonomics intervention

IV.5.4.1. Introduction of Correct Work Posture Reminder (CWPR) figure

Altough immediate outcomes of training were quite encouraging, it was taken into account that ergonomics information could have lost effect through hard work days. In order to attain behavioral change of operators, which was primary target of ergonomics improvements and to constantly remind operators of correct work postures at sewing workstation, a Correct Work Posture Reminder (CWPR) figure was designed and printed in color. CWPR figure included a model picture of an operator maintaining correct work posture and key instructions to direct operators toward neutral back, neck and wrist posture. Instructions were worded simple, concise and in active voice to be effective according to technical communication principles (Hartley, 1981). Design and installation of CWPR figure was showed in figure below.

Figure IV.6. Correct Work Posture Reminder Figure

There is evidence that coupling prose material with illustrations not only contributes to hazard conveyance and comprehension of visual warnings but also facilitates behavioral compliance with instructions (Roger *et al*, 2000). In this respect, operator picture in CWPR figure was intended to provide a postural model and criterion to guide operators for self-adjusting their workstations. CWPR Figures were installed on all workstations in project lines within operators'sight immediately after ergonomics training. In order to attract operators' attention, figures were placed over sewing machines when possible and on sewing machine tables otherwise.

Albeit majority of ergonomics programs, participatory ergonomics case studies or ergonomics interventions involve training, design and introduction of CWPR figure was not found in literature (Herbert *et al*, 2001, Pun *et al*, 2004, Bezjak and Knez, 1995, Kelly and Ortiz, 1992, Ellegast and Herda, 2004, Quintana and Alonso, 2002/2003). This intervention was a simple, very low cost and effective way to achieve behavioral change towards more neutral and healthy posture which would diminish ergonomics risks.

After training and installation of CWPR figure, operators were frequently interviewed in their workplace. It was observed that acceptance of CWPR figure was high among operators. Combined with training and ergonomics manual, design and installation of CWPR figures particularly for operators helped to convey importance of project and their well-being for Talu management. Progression of interventions contributed positively to their self-esteem and enhanced their support for project. Operators were observed to appreciate sincere effort put to adress occupational health issues. They reported that they were trying to comply with correct work posture instructions as much as possible and CWPR figures were helpful in recalling how to maintain their postures and how to adjust workstations.

IV.5.4.2. Workstation adjustments

Sewing workstation has not been subjected to major changes for eras. A typical sewing workstation includes sewing machine, sewing table, a chair, boxes to hold material and foot pedals. It was clearly known that, workstation should be adjusted to enable operators to adopt ergonomically correct work postures. Adjustability is an important feature for workstation components such as chair, table or foot pedal from ergonomics standpoint (Quintana and Alonso, 2002/2003). Several authors achieved ergonomics improvements in garment industry through workstation adjustments.

Herbert *et al*, (2001), evaluated the impact of adjustable chairs on MS disorder rate and severity in a garment manufacturing company through a joint labor-management ergonomics intervention program. They reported that after installation of the adjustable chairs reported pain and exposure to awkward postures decreased significantly.

Bezjak and Knez, (1995), improved sewing workstation by extending machine table and attaching a shelf for depositing. These improvements were found to allow operators sit more neutral and reduced awkward bending of back.

Kelly and Ortiz, (1992), conducted ergonomics analysis and intervention in three apparel manufacturing companies in southeastern US. They first collected anthropometric data on workers due to relevant findings that garment workers had different dimensional characteristics from population norms. Approximately half of the participants reported pain in upper back, neck and right hand. Obstructions beneath the sewing machine (e.g. engine, equipment) were found to hinder easy access to workstation. They installed ergonomic sewing chairs, tilted workstation tops and trained workers on how to adjust their workstations. After 5 weeks of trial use, frequency of MS discomfort and back angle was reduced.

Ellegast and Herda, (2004), used a computer assisted MS load analysis system to undertake interventions in sewing workplace. Analysis system enabled them to measure variety of body angles, which indicated areas with potential MS discomfort. They identified physical load factors by computer system and redesigned sewing workstations according to ergonomics principles. New designs included adjustability of work surface, sit/stand optional work position and tilt adjustment of the work surface. They found that body angles decreased significantly toward neutral positions.

Quintana and Alonso, (2002/2003), analyzed effect of work station adjustability on work postures in sewing task. They demonstrated that excessive body angles could be significantly reduced to neutral positions by adjusting the workstation in line with ergonomics principles. They emphasized the importance of adjustability of work equipment in maintaining correct work posture.

Delleman and Dul, (2002), suggested that 11^o inclination of table and adjustable pedal would contribute to seating comfort in machine sewing task. They investigated effects of desk height (i.e. +5, +10, +15 cm. above elbow height), desk slope (i.e. 0^o and 10^o) and pedal position (i.e. -4 cm and +6 cm. from needle) on posture and perceived comfort. They reported that higher desks and 10^o slope lead to more neutral head, neck and trunk postures. According to perception of workers, desk was recommended to be at least 5 cm. above elbow height. Operators preferred 10^o slope than flat desk which supported that usefullness of desk slope. Furthermore, adjustability of foot pedal was also recommended.

Chan *et al*, (2002), implemented a set of basic ergonomic improvements in sewing workplace. They tilted sewing machine table 4^o by putting a piece of wood under table legs and contributed to production of an "improved" sewing chair which could meet requirements of workers. Additionally they extended table to reduce awkward arm postures and pinch forces for large clothes. They involved workers in improvement efforts in a participatory approach and these adjustments were reported to be well accepted.

As showed in abovementioned studies, workstation adjustments form the core of ergonomics improvements in machine sewing environment. Low postural variability, static, sedentary and repetitive nature of sewing task necessiate and contribute to importance of workstation adjustments. Certain factors that prevailed in natural manufacturing context of Talu Textile lead to development of self-adjustment approach. First factor was substantial variability in antropometric measures of workforce which comprised a group of both genders, age and body dimensions of whom differ in a wide range. Thus, adjusting all workstations to specific measures was not applicable. Second factor was constant rotation of operators over different machines. Within manufacturing flow in Talu Textile, operators could be assigned to different machines anytime. Altough majority of operators were specialized in a certain type of sewing machine, they can be rotated over different types of sewing machines at their lines and seating order of operators in lines can be also altered within work flow. Rotation required that operators should adjust different machines themselves, without an external help to keep up with sewing task while maintaining correct postures in new workstation.

Third factor was consideration of participation and macro ergonomics issues. Control over design and pace of work was recognized as a significant value for modern professional life since early 90's (Hendrick, 1991). Macro-ergonomics approach suggests that interventions should involve managerial perspectives rather than confining ergonomics movements in micro-interventions (Halpern and Dawson, 1997). It was strongly recommended in participatory ergonomics and macro ergonomics concepts that employees should be given control over their work life (Noro, 1991). Adoption of participatory and macro-ergonomic approaches was suggested not only to facilitate administration of but also to increase positive outcomes of ergonomics practices (Nagamachi, 1995, Hendrick, 1991). Sullivan and Corlett, (1998), provided evidence that while transferring ergonomics knowledge and enabling employees to diagnose ergonomics problems was of great help for continuous improvement of workplaces, giving employees control over their work could be achieved through self-adjustment approach. Self-adjustment approach for workstation adjustment interventions was considered to serve these purposes. Sewing operators did not have a significant control over their work. Self-adjustment would lead to empowerment of operators by equipping them with knowledge and authorization to make conscious changes in their own workplace, which was compatible with participatory and macro ergonomics concepts. Self-adjustment would also provide control over their work to a certain degree. Hence, self-adjustment was considered more applicable and usefull for workstation adjustment interventions.

In a proactive manner, necessary and sufficient ergonomics knowledge about objectives and practices of workstation adjustments were given to operators in ergonomics training which was designed partly as an interactive workshop. Subsequent to training and placement of CWPR figures on workstations, in cooperation with floor supervisors, each operator was interviewed individually about workstation adjustments he/she needed to maintain desired postures. Operators were also informed about how to benefit from adjustability dimensions of machine sewing workstation; height of backrest and seat of chair, height of sewing table, location and slope of foot pedal. They were encouraged to make necessary changes to fit their posture to model picture in CWPR figure.

A maintenance team of two technicians was assigned to carry out machine adjustment and repairment task in Talu Textile. This maintenance team was involved in interventions by sewing department supervisor. They were broadly informed about QUITE project by the author as new members of participation group. They were supportive of the ergonomics effort and contributed creative ideas on possible adjustments. It was observed that operators requested adjustments (e.g. changing location of foot pedal) from maintenance team in line with ergonomics training.

In order to follow-up outcomes of training, introduction of CWPR figure and workstation adjustments operators were frequently interviewed afterwards. It was observed that employees could identify inadequacies of their workstation such as low chair or incorrect location of foot pedal. Prevalent workstation problem was vicinity of foot pedal to body. Ergonomically, foot pedal should be distant enough from body in order to let upper body approach to machine and maintain an upright posture. Majority of requests to maintenance team addressed position of pedal. It was further observed that operators were content with participatory approach and ability to make changes in workplace. Self-adjustment approach proved to be useful in that operators could identify ergonomics problems and tried to apply ergonomics principles individually.

IV.5.4.3. Tilting adjustments

Table slope is a widely investigated sewing workstation design variable and number of studies have shown that tilting sewing machines toward operators remarkably served to maintain neutral work postures (Chan *et al*, 2002, Delleman and Dul, 2002, Ellegast and Herda, 2004, Kelly and Ortiz, 1992, Li *et al*, 1995). Main purpose of tilting table is to reduce visual discomfort by increasing visibility of operation point (VOP), which leads to reduction in neck and trunk flexion. In literature two tilting methods were proposed; tilting table while keeping machine straight or tilting both table and machine. It was proposed that tilting table while keeping machine straight would increase VOP more than tilting both table and machine. While operation point was to be enlarged in former, tilting machine in big angles would obstruct VOP in latter method. Another concern was ease of sewing operation in that operators have to move clothe forward on a positive slope which could be harder than flat position. Thus, determining the optimum tilting angle is important in balancing reduction of visual discomfort and ease of operation. Numerous authors have investigated optimum angle and practiced tilting adjustments.

Li *et al*, (1995), investigated effect of table slope and needle angle on postural comfort of sewing machine operators in experimental settings. They found that table slope of 20^o significantly reduced trunk flexion and needle angle of 10^o significantly reduced head/neck flexion, which improved viewing angle and lead to a more comfortable work posture. They reported that operators could maintain neutral work posture for longer periods. Subjective ratings supported that these improvements were taken positively by operators. Delleman and Dul, (2002), reported that 10^o slope lead to a more upright head, neck and trunk positions in sewing task. Sewing operators reported preference toward 10^o slope than flat desk. However, these two case studies were conducted in laboratory settings. Following case studies investigated effects of tilting adjustments in natural machine sewing context and demonstrated that lower angles were more applicable in manufacturing environment. Kelly and Ortiz, (1992), tilted sewing workstation tops, trained workers about how to adjust their workstations and achieved reduction in frequency of MS discomfort and back angle after 5 weeks of trial use. Ellegast and Herda, (2004), applied tilting adjustments and achieved significant reduction in body angles toward neutral positions. Chan *et al*, (2002), tilted sewing machine table 4^o by putting a piece of wood under table legs within a set of ergonomics interventions. They attained employee participation in improvement efforts and these adjustments were reported to be well accepted. An example of practical tilting adjustment was presented in figure below.

Figure IV.7. Machine Tilting Example (OSHA Offical web site)

Based on literature survey, tilting sewing machines was selected as an intervention method which targeted correcting work postures, reduction of MS discomfort and reduction of SORD by improving VOP. Whilst it was proposed to and agreed upon with managers during interviews and in analysis report, operators were made familiar about tilting alternative during training sessions.

Having completed aforementioned workstation adjustments, applicability of tilting tables was discussed in detail with sewing department supervisor and maintenance team. Of different sewing machines used in a typical sewing line, most weightly used machine was single-needle straight-stitch type. Function of single-needle straight-stitch machines was to join to pieces of fabric with a row of single stitches. Various sewing tasks can be performed by using these machines such as stitching collars or pockets. Also, all relevant case studies in literature involved single-needle straight-stitch machines which pointed to potential success of the intervention. In these respects, tilting was planned to be applied to straight-stitch sewing machines. Tilting was a completely new idea for company personnel and discussion raised some technical concerns. Sewing machines were attached to tables. Nearly half of sewing machines had open oil box placed beneath the body of machine, while remaining machines, comperatively newer models, had closed oil system in which oil was circulated through plastic pipes. For open-oil-box machines, oil leak risk was anticipated in case of tilting table and machine more than a certain angle. For closed-oil-system machines, it was needed to assure that tilting would not cause any harm on functioning of the machines.

In order to investigate this problem, author arranged a meeting with technical manager of ASTAŞ, supplier of Talu Textile which distributed and provided technical service for sewing machinery. Possible consequences of tilting tables were discussed, sewing machines were examined and effect of tilting on oil circulation system was investigated during the meeting. It was concluded that while oil leak was possible for open-oil-box machines, tilting adjustment would not cause any harmful effect for functioning of closed-oil-system machines. Subsequently, information gathered during meeting was conveyed to participation group and four machines in first line were planned to be tilted as a trial application.

In a participatory approach, sewing department supervisor, author and maintenance team sought to find a low-cost, practical method for tilting tables. As a practical application model, Chan *et al*, (2002) propounded that 4^{o} table slope would be well accepted by operators and putting a wood under table legs was proposed as a simple method for tilting machines. Since machines were attached to table, both machine and tabletop should have been tilted. However, machines were to be rotated across lines as necessary, and therefore they had wheels. Thus it was not reasonable neither to remove these wheels and to put another part under the machines for tilting nor to change structure of machines since it would incure considerable costs. This technical problem was solved through employing principles of Theory of Inventive Problem Solving (TRIZ), an inventive problem solving method (Webb, 2002), at micro level.

TRIZ, theory of which is beyond the scope of present study, was reported to be effective in solving knotty technical and mainly design problems within a systematic approach (Leon, 2003, Kim and Cochran, 2000, Webb, 2002). It involves 39 generalized design parameters which contradict in essence of the problems investigated and 40 inventive principles that serve to resolve these problems. A primary tool of TRIZ is contradicton matrix which demonstrates the parameters that is targeted to improve, contradictory parameters that would be adversely affected and inventive principles employed to reach a solution. Contradicton matrix for tilting adjustment problem was given below.

Table IV.9. TRIZ Contradiction Matrix for Tilting Adjustment

<table>
<tr><th>Affected parameter→
↓Improving parameter</th><th>Shape</th><th>Stability of object’s composition</th></tr>
<tr><td>Manufacturing precision</td><td colspan="2" rowspan="3">Inventive principles
1 Segmentation 4 Asymmetry
16 Partial action
27 Cheap and short-living objects</td></tr>
<tr><td>User-friendlines</td></tr>
<tr><td>Productivity</td></tr>
</table>

It was assessed that while manufacturing precision in sewing task, user-friendliness and operator productivity would be improved via tilting adjustment, shape and stability of current machines would be affected. First inventive principle applied was segmentation. It was thought to tilt table top and machine attached to it instead of whole machine with table legs. Maintenance team found it applicable to separate table top from lower parts of table. Second principle applied was asymmetry. It was thought to apply asymmetrical tilting, by giving a positive slope to table top causing asymmetry, while maintaining symmetry of lower parts. Third principle applied in parallel with segmentation was partial action; preferring tilting table top and machine instead of whole structure of sewing machine and table. Last principle was using cheap objects for tilting. Maintenance team planned to lift far end of table by placing rivets between table top and two table legs which would provide a positive slope as intented.

Slope of 4^0 was considered adequate in line with literature. Higher table slope would be possible by using more rivets. It was found that 3 rivets at each side provided 4.2^0 of table slope, which would suffice for intervention (Chan *et al*, 2002). Initially, tilting adjustment was applied to four of suitable machines for trial use.

Operators at tilted machines were intervewed for initial observations and were encouraged to share their opinions about tilted machines in a participatory approach.

Trial use continued for two weeks. Meanwhile operators at tilted machines were periodically intervewed and encouraged to make assessments emphasizing that their opinion would be very valuable for advancement of the project. It was observed that having a say on progress of project enhanced operators' support for interventions. In the aftermath of trial use, operators were interviewed about preference toward tilted machines together with line and department supervisors. Operators were supportive of tilting adjustment in that it provided improved VOP and enabled them to see the flow of sewn cloth beyond the needle. Maintaining more neutral positions was reported to be easier at tilted machines and position of the arms was found more comfortable. Adjusted slope did not cause sliding of the cloth over table, thus, no measure was taken such as covering the table top with a material to prevent sliding (Chan *et al*, 2002). Department supervisor was also supportive of extending tilting adjustment to all suitable machines in project lines.

Outcomes of trial use of tilted machines were presented to CEO of Talu Textile and it was planned to apply tilting adjustment to all of the 15 single-needle single-stitch machines in project lines with closed oil system. Tilting adjustments were completed by maintenance personnel. After completion of adjustments, operators were interviewed and it was observed that they were content with tilted machines. Rotation enabled great portion of operators to have experience with tilted machines. They continued to report that it was easier to maintain correct work postures in tilted machines, which implied that combined influence of ergonomics training, CWPR figure, workstation and tilting adjustment was achieved. Tilting adjustments were illustrated in figure below.

Figure IV.8. Tilting Adjustments in Machine Sewing Workstation

IV.5.5. Monitoring change in ergonomics risks/problems: Application of ERA questionnaire and QEC after interventions

IV.5.5.1. Participants

ERA questionnaire and QEC were conducted after interventions with a group of 30 sewing operators (13 males, 17 females) that were involved in QUITE project. Their mean age was 30.16 years and mean tenure at job of 47 months. Percentage of elementary, secondary and high school graduates were 60 %, 33,3 %, 6,7 % respectively. Of 30 participants, 19 operators (63 %) were from Line 1 and 11 operators (37 %) were from Line 2. Videotaping for QEC was performed with all operators. Practical conditions constrained sample group; one of the operators in previous participant group was at military service and five of the operators had quit the job. 15 Operators experienced tilted machines. None of the participants had received physical theraphy since first survey.

IV.5.5.2. Application of ERA questionnaire and QEC

After interventions, ERA questionnaire and QEC were re-applied in late October 2005. Surveys were administered in same settings in order to avoid any undesired affect. ERA questionnaire and "Worker's Assessment" part of QEC was conducted in interview settings in the same room near machine sewing department. Participants were sent to survey room successively by floor supervisors so that work flow was not disturbed by their absence. Each participant was given instructions regarding to survey and privacy of responses. They were informed that objective was to assess effect of interventions and progress of the project. In order to assure anonymity, "participant number" method, which proved to be effective in first survey was undertaken. Participants were asked to fill ERA questionnaire form and they were given necessary help in understanding and responding to items. Questions regarding to perceived usefullnes were added to ERA questionnaire. "Worker's Assessment" part of QEC was completed interactively. Completion of each questionnaire and "Worker's Assessment" part of QEC took about 15 minutes.

After all participants completed ERA questionnaire and "Worker's Assessment" parts of QEC, work postures were videotaped for "Observer's Assessment" part of QEC during afternoon period. Same Samsung SCL 860 8mm. camera was used for videotaping. "Participant number" label was received back from each operator and screened by camera. Videotaping of each employee took about 5-10 minutes. "Observer's Assessment" part of QEC was completed aftermath via analysis of videotapes. ERA questionnaire and QEC form of each participant was matched using participant number screened on video recordings. Analysis was completed successfully without compromising anonymity.

IV.5.5.3. Results of ERA questionnaire and QEC

In perceived usefulness part, it was asked to participants if they found ergonomics interventions undertaken within QUITE project useful. Results of perceived usefulness part, including neutral answers were shown in table below.

Table IV.10. Perceived Usefulness of Ergonomics Interventions

F. Did you find interventions undertaken within QUITE project useful?	N	NEUTRAL (%)	NO(%)	YES(%)
1.Ergonomics training	30	1 (3,33)	3 (10,0)	26 (86,67)
2.Ergonomics manual	30	2 (6,67)	2 (6,67)	26 (86,67)
3.Correct posture reminder	30	1 (3,33)	7 (23,33)	22 (73,3)
4.Tilting adjustments	15	3 (20)	2 (13)	10 (67)
5.Workstation adjustments	30	1 (3,33)	1 (3,33)	28 (93,33)

It was revealed that all interventions were found to be highly useful by operators. Tilting adjustment was evaluated by solely those who experienced operation with tilted machines. It was stated that participatory approach and focus on occupational health issues was remarkably well taken and project contributed not only to ergonomics issues but also motivation and job satisfaction.

It was further asked if participants observed reduction in MS discomfort after interventions. Summary of answers about perceived reduction in MS discomfort was given below.

Table IV.11. Level of Perceived Reduction in MS Discomfort after Interventions

Did you experience a decrease in MS discomfort compared to discomfort level before interventions? (n=30)	
NO(%)	YES(%)
17 (56,67)	13 (43,33)

It was found that 13 (43.33 %) participants reportedly felt reduction in MS discomfort, which was quite encouraging about success of QUITE project and interventions. It was detected that number of participants who used tilted machines in this cohort was 6 (46 %) while remaining 7 (54 %) did not have experience with tilted machines. This result implied positive effect of ergonomics interventions. Difference between MS discomfort severity ratings and frequency of physical ergonomics risk ratings of operators who reported perceived reduction in MS discomfort (n=13) before/after ergonomics interventions was analysed using Wilcoxon Sign Rank (WSR) test and results of this analysis were presented in further parts.

Preliminary Anderson-Darling test on ERA questionnaire ratings showed that data violated normality. Analysis of before/after intervention results necessitated paired comparisons. Nonparametric tests were recommended when normality assumption for parametric tests is violated and paried groups of comparison were involved (Devore, 1995). Two nonparametric tests; Wilcoxon Sign Rank (WSR) test for paired data and Mcnemar's test to compare changes in number group members were widely applied in and recommended for before/after analysis. Numerous studies in ergonomics literature exemplify use of WSR and Mcnemar's tests for before/after analysis of severity and prevalence of ergonomics problems (Aborg *et al*, 1998, Alexandre *et al*, 2001, Herbert *et al*, 2001, Yeow and Sen, 2003). Hence, while WSR test was used to evaluate difference between severity/frequency of ergonomics risks, Mcnemar's test was used to evaluate difference between MS discomfort prevalence before/after ergonomics interventions (i.e. $\alpha = 0.05$). Results of part A, B, C and D of ERA questionnaire before/after ergonomics interventions, WSR test values and significance levels were presented in table below.

Table IV.12. Results of ERA Questionnaire Part A, B, C and D, WSR Test Values and Significance Levels

A.Do you feel discomfort by… Anchors: No(1) Slightly(2) Moderately(3) Severely (4)						
	BEFORE (n=30)		AFTER(n=30)		Wilcoxon Sign Rank Test	
	Mean	Std.d	Mean	Std.d	Z	P
A1.Noise	2,000	,946	2,300	,9523	1,214	,887
A2. Lighting	1,366	,614	1,533	,8193	1,311	,905
A3.Climate	2,533	1,279	2,866	1,008	1,371	,915
A4.Air quality	2,766	1,006	2,866	,9371	,905	,818
B.Do you feel discomfort in using.. Anchors: No(1) Slightly(2) Moderately(3)Severely (4)						
	BEFORE(n=30)		AFTER(n=30)		Wilcoxon Sign Rank Test	
	Mean	Std.d	Mean	Std.d	Z	P
B1.Sewing machine	1,233	,568	1,266	,520	,333	,630
B2.Table	1,066	,253	1,100	,305	,577	,718
B3.Chair	1,133	,345	1,233	,430	1,342	,909
B4.Pedal	1,133	,434	1,300	,466	1,387	,917
B5.Hand tools	1,233	,430	1,366	,668	1,155	,876
C.During work, do you… Anchors: No(1) Sometimes(2) Frequently(3) Always(4)						
	BEFORE(n=30)		AFTER(n=30)		Wilcoxon Sign Rank Test	
	Mean	Std.d	Mean	Std.d	Z	P
C1.Bend your upper body?	2,900	1,061	2,066	,9072	-3,473	,000
C2.Bend your neck?	2,766	1,222	2,333	,8023	-2,003	,023
C3.Feel visual discomfort?	1,666	,8023	1,400	,6747	-1,496	,068
C4.Feel obstructed by engine etc. Underneath the table?	1,066	,2537	1,133	,345	1,414	,921
C5.Have to reach extensively?	1,566	,6789	1,533	,7303	-,037	,486
C6. Bend your wrists?	2,966	1,217	1,966	,9279	-3,453	,000
C7. Lean your arms on sharp edges?	1,566	1,040	1,266	,5833	-1,778	,038
C8.Find your rest breaks insufficient?	1,266	,6397	1,200	,6644	-1,00	,159
D. Answer the following questions. Anchors: No(1)Slightly(2)Moderately(3)Severely (4)						
	BEFORE(n=30)		AFTER(n=30)		Wilcoxon Sign Rank Test	
	Mean	Std.d	Mean	Std.d	Z	P
D1.Does your work require mental effort?	2,366	,927	2,800	,924	1,562	,941
D2.Does your work involve error risk?	2,766	,858	2,400	,894	-1,852	,032
D3.Is your job monotonous?	1,966	1,033	1,933	,944	-,206	,419

Results showed no significant difference (i.e. $p > 0.05$), between before/after severity of discomfort caused by environmental factors in part A, which was anticipated as interventions did not adress these factors. Incremental increases in discomfort due to noise, ligthing and low air quality could be attributed to enhanced ergonomics awareness of operators. Workstation elements in part B had not introduced severe ergonomics problems before interventions and no significant reduction was found (i.e. $p > 0.05$), after ergonomics interventions. Of cognitive factors in part D, solely error risk was rated to be significantly reduced (i.e. p: 0.032 < 0.05). Reduction in error risk could be attributed to higher visual and postural comfort introduced by tilted machines which provided improved visibility of operation point and flow of clothe.

Remarkable changes were obtained in part C which included exposure to physical ergonomics risks. Reduction in frequency of exposure to physical ergonomics risks was shown in figure below.

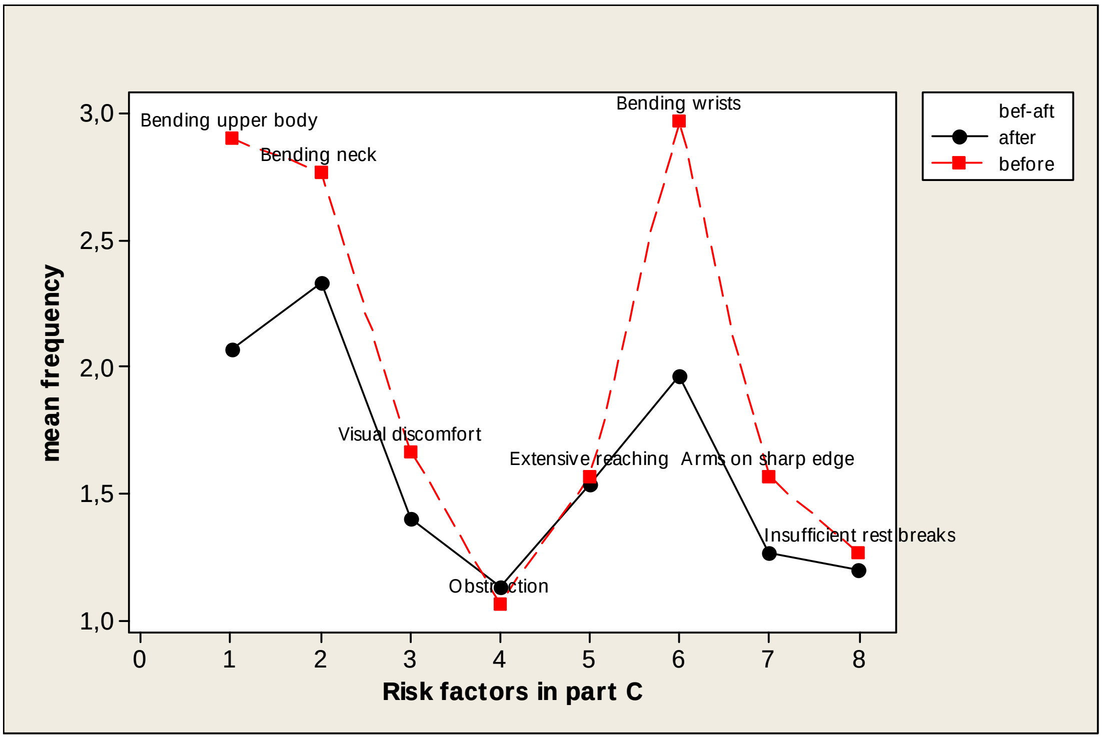

Figure IV.9 Results of Part C of ERA Questionnaire Before/After Ergonomics Interventions

Ergonomics interventions aimed behavioral change toward correct work methods and significantly lower frequencies of bending upper body (i.e. p: 0.000 < 0.05), neck (i.e. p: 0.023 < 0.05), wrists (i.e. p: 0.000 < 0.05) and leaning arms on sharp edges (i.e. p: 0.038 < 0.05), revealed accomplishment of this objective. Incremental reduction in visual discomfort indicated that interventions posited potential for greater minimization of these risks in longer terms.

Part E of ERA questionnaire which adressed MS discomfort was evaluated in both prevalence and severity aspects. As was the case with first analysis, prevalence of MS discomfort across anatomic sites was evaluated by counting “No” responses as an indication of absence of MS discomfort, while counting all other responses, which involved discomfort to a certain degree, as an indication of presence of MS discomfort. Severity of MS discomfort was evaluated by mean rating values. Differences between prevalence and severity of MS discomfort before/after ergonomics interventions were assessed using Mcnemar’s test and WSR test respectively. Prevalence of MS discomfort before/after ergonomics interventions and Mcnemar’s test significance levels were presented in Table IV.11 below.

Table IV.13. Prevalence Results of Part E and Mcnemar’s Test Significance Levels

E. Do you feel discomfort (ache, pain, numbness, tingling etc.) in ...					
	BEFORE		AFTER		Mcnemar’s Test
	YES – n (%)		YES – n (%)		P
Neck	19	63,3	16	53,3	, 303
Right shoulder	14	46,7	13	43,3	,500
Left shoulder	11	36,7	10	33,3	,500
Upper back	20	66,7	18	60	,364
Low back	23	76,7	22	73,3	,500
Right arm	9	30,0	11	36,7	,387
Left arm	9	30,0	9	30	,500
Right wrist	5	16,7	6	20,0	,500
Left wrist	3	10,0	5	16,7	,344
Right hand	4	13,3	5	16,7	,500
Left hand	1	3,3	3	10,0	,312
Right leg	13	43,3	15	50	,387
Left leg	18	60,0	14	46,7	,062
Right foot	6	20,0	9	30,0	,275
Left foot	11	36,7	12	40,0	,500

Results revealed that aside from incremental reduction in upper extremities, there was no significant change (i.e. $p > 0.05$) in MS discomfort prevalence. Albeit a slight reduction was attained, MS discomfort was not significantly reduced. It was considered that primary behavioral change towards neutral and healthy work practices would lead to reduction of underlying risks and reduction of MS discomfort in longer terms.

Severity of MS discomfort before/after ergonomics interventions, WSR test values and significance levels were presented in table below.

Table IV.14. Severity Results of Part E, WSR Test Values and Significance Levels

E. Do you feel discomfort (pain, numbness, tingling etc.) in ...

Anchors: No(1) Slightly(2) Moderately(3) Severely (4)

	BEFORE		AFTER		Wilcoxon Sign Rank Test	
	Mean	Std.d	Mean	Std.d	Z	P
Neck	2,066	1,014	1,833	,8743	-1,334	,091
Right shoulder	1,766	1,006	1,633	,850	-,667	,252
Left shoulder	1,666	1,028	1,666	1,061	,000	,500
Upper back	2,433	1,222	2,100	1,125	-1,451	,074
Low back	2,333	1,028	2,433	1,135	,361	,641
Right arm	1,466	,819	1,633	,927	,766	,778
Left arm	1,433	,773	1,400	,674	-,291	,385
Right wrist	1,300	,794	1,466	1,008	,779	,782
Left wrist	1,200	,610	1,366	,889	1,035	,849
Right hand	1,233	,678	1,400	,932	,779	,782
Left hand	1,100	,547	1,233	,773	,756	,775
Right leg	1,600	,770	1,933	1,080	1,511	,935
Left leg	2,033	,999	1,866	1,074	-1,155	,124
Right foot	1,400	,855	1,533	,937	,601	,726
Left foot	1,733	1,087	1,700	1,022	-,203	,420

Altough incremental reductions were obtained in some of the upper extremities, there was no significant change (i.e. $p > 0.05$) in severity of MS discomfort overall anatomic sites. Similar with assessments about prevalence results, primary reduction of underlying risks as obtained in part C, was expected to result in reduction of MS discomfort particularly at upper extremities in longer terms.

Pareto analysis of reported MS discomfort was replicated after ergonomics interventions and Pareto diagram of MS discomfort across body areas was given in figure below.

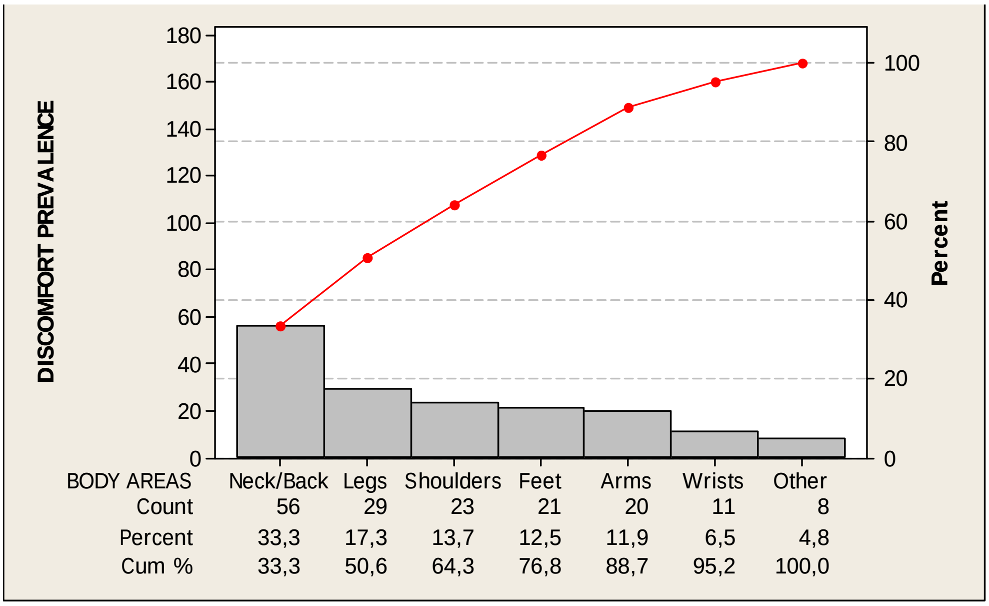

Figure IV.10. Pareto Diagram of Reported MS Discomfort after Ergonomics Interventions

Results showed that reported MS discomfort at neck/back, legs and shoulders were ranked in the top three body areas after ergonomics interventions. While reported discomfort at those three areas comprised 70.7 % of all reported discomfort before ergonomics interventions, this percentage occurred to be 64.3 %.

An important intervention was tilting adjustment. Demographics showed that 15 of the participants was assigned to tilted sewing machines. In order to explore possible effects of tilting adjustment from ergonomics standpoint, Analysis of variance (ANOVA) was performed on MS discomfort severity ratings and frequencies in part C of ERA questionnaire produced by operators who used tilted or flat sewing machines. ANOVA showed that MS discomfort severity ratings of two groups were not significantly different. Nonetheless, MS discomfort severity reported by operators using tilted machines were incrementally lower in majority of body parts (e.g.shoulders, upper and lower back) compared to that of reported by operators using flat machines. Results of this analysis were presented in Appendix-B.

ANOVA was performed on mean frequencies of exposure to ergonomics risk factors. However, similar with MS discomfort severity, while no significant difference was detected between ratings of two groups, majority of physical ergonomics risk factors reported by operators using tilted machines had incrementally lower frequencies compared to that of reported by operators using flat machines. Results of this analysis were presented in Appendix-B.

Findings in both analyses supported that tilting machines had merit to enable operators maintain ergonomically correct work postures which would result in lower MS discomfort. These positive improvements were deeemed likely in case tilted machines would be kept in use for long terms.

It was mentioned above that 13 (43.33 %) participants reportedly felt reduction in MS discomfort. This result was considered to imply positive effects of ergonomics interventions. Difference between MS discomfort severity ratings and frequency of exposure to physical ergonomics risks reported by operators who perceived reduction in MS discomfort (n=13) before/after ergonomics interventions were analysed using WSR. Results showed that MS discomfort severity ratings of operators who reported reduction in MS discomfort were decreased at particularly upper extremities incrementally though not significantly. It was considered that MS discomfort would continue to decrease in longer term if correct work methods introduced through ergonomics interventions could be maintained. Results of this analysis were presented in Appendix-B.

It was further explored if this incremental reduction in MS discomfort was aligned with reduced frequency of exposure to physical ergonomics risks and results of this analysis were presented in table below.

Table IV.15. Mean Frequencies in Part C of ERA Questionnaire Given by Operators Who Reported Reduction in MS Discomfort after Ergonomics Interventions, WSR Test Values and Significance Levels

C.During work, do you… Anchors: No(1) Sometimes(2) Frequently(3) Always(4)						
	BEFORE(n=13)		AFTER (n=13)		Wilcoxon Sign Rank Test	
	Mean	Std.d	Mean	Std.d	Z	P
C1.Bend your upper body?	3,307	,854	2,461	,967	-2,414	,008
C2.Bend your neck?	2,923	1,187	2,384	,869	-1,327	,093
C3.Feel visual discomfort?	1,846	1,068	1,307	,480	-1,811	,035
C4.Feel obstructed by engine etc. underneath the table?	1,076	,277	1,307	,630	1,342	,910
C5.Have to reach extensively?	1,769	,832	1,538	,967	-,517	,303
C6. Bend your wrists?	3,076	1,255	2,153	,898	-2,280	,012
C7. Lean your arms on sharp edges?	1,538	1,126	1,384	,650	-,743	,229
C8.Find your rest breaks insufficient?	1,230	,438	1,153	,554	-,577	,282

Significant reduction in frequency of awkward postures (i.e. bending upper body and wrists with *p*: 0.016 < 0.005 and 0.023 < 0.005 respectively) indicated that operators who reported reduction in physical discomfort after ergonomics interventions have adopted correct work postures. Also, significant reduction in frequency of feeling visual discomfort (i.e. *p*: 0.035 < 0.05), was deemed to increase perceived reduction in MS discomfort.

Second part of analysis after ergonomics intervention was QEC. QEC Body areas and risk factors, proposed MS risk levels were presented below for ease of reference (David *et al*, 2005).

Table IV.16. QEC Body Areas and Risk Factors, Proposed MS Risk Levels (David *et al.*, 2005)

	MS Risk Levels			
QEC Body Areas and Risk Factors	Very High	High	Moderate	Low
Back(Static)	29-40	23-29	16-22	8-15
Shoulder/Arm	41-56	31-40	21-30	10-20
Wrist/Hand	41-46	31-40	21-30	10-20
Neck	16-18	12-14	8-10	4 - 6
Workpace	-	9	4	1
Stress	16	9	4	1

Differences between QEC scores before/after ergonomics interventions were evaluated via WSR test (i.e. $\alpha = 0.05$). Driving and vibration scores were excluded in analysis due to irrelevance of these factors in research. Mean QEC scores, MS risk levels, WSR test values and significance levels were presented in table below.

Table IV.17. Mean QEC Scores, MS Risk Levels, WSR Test Values and Significance Levels

QEC Body Areas and Risk Factors	**BEFORE (n=30)**			**AFTER (n=30)**			**WSR**	
	Mean	Std.d.	Risk Level	Mean	Std.d.	Risk Level	**Z**	**P**
Back(Static)	26,400	1,610	High	24,933	2,333	High	-2,84	,003
Shoulder/Arm	33,466	1,736	High	30,933	2,016	Moderate	-3,65	,000
Wrist/Hand	25,200	1,627	Moderate	23,866	2,029	Moderate	-2,67	,004
Neck	17,466	,899	Very High	14,866	1,252	High	-4,59	,000
Workpace	4,600	2,457	Moderate	4,700	2,365	Moderate	,108	,540
Stress	7,733	4,258	Moderate	7,533	4,939	Moderate	-,216	,414

Results demonstrated substantially significant reductions in QEC scores and MS risks, which pointed to positive effects of ergonomics interventions. It was revealed that back, shoulder/arm, wrist/hand and neck scores were decreased significantly with *p* values 0.003 < 0.05, 0.000 < 0.05, 0.004 < 0.05 and 0.000 < 0.05 respectively, which indicated that operators adopted ergonomically improved work practices towards neutral postures and lower risks. Reduction in QEC scores were clearly demonstrated in figure below.

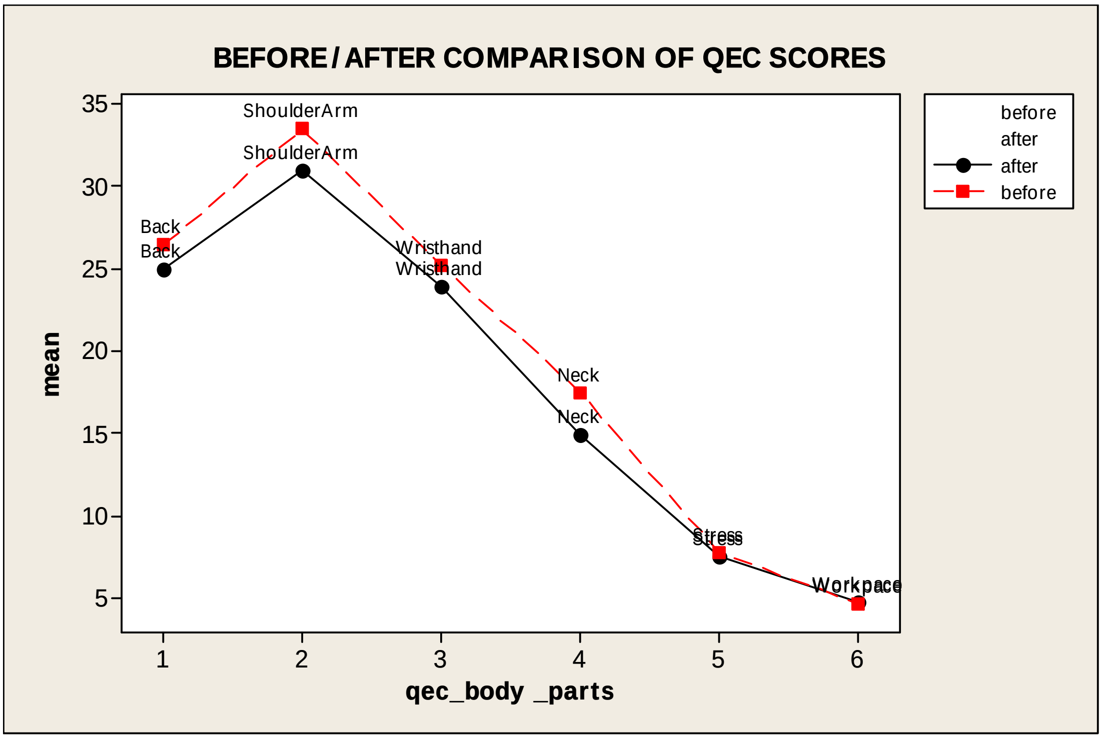

Figure IV.11. QEC Scores Before/After Ergonomics Interventions

IV.5.5.4. Assessment of changes in ergonomics problems/risks

Before interventions, ergonomics risks/problems were identified through ERA questionnaire and QEC, supplemented by qualitative data. Ergonomics interventions aftermath targeted risks that could be eliminated or reduced via low-cost undertakings. In summary, those ergonomics risks/problems were; static and awkward work postures, lack of training about ergonomics issues and correct work practices, visual demand, workstation adjustments, MS discomfort prevailing in upper extremities. Risk factors that entailed costly interventions such as low air quality or noise were kept out of the scope of present study.

Ergonomics risk factors were addressed by interventions implemented in participatory approach; ergonomics training and correct work methods manual, placement of correct work posture reminder figure on machines, workstation adjustments and tilting adjustments. This set of low-cost interventions provided basic ergonomics conscious and served to attain behavioral change towards correct work practices such as maintaining neutral positions.

Changes in ergonomics risks/problems after interventions were monitored via replication of ERA questionnaire and QEC in same conditions after three months.

It was revealed in part C of ERA questionnaire addressing physical ergonomics risks that, significant reductions were attained in frequency of awkward postures; bending upper body, neck and wrists and frequency of feeling visual discomfort. This reduction pointed to behavioral change towards neutral postures, which signified an improvement from ergonomics standpoint. This reduction was supported by highly significant reductions in MS risks as shown by QEC results. QEC scores for back, shoulder/arm, neck and wrist/hand were significantly decreased after ergonomics interventions. Though not significant, incremental reductions in MS discomfort severity across upper extremities were identified which supported effectiveness of ergonomics interventions.

It was observed during periodical informal interviews with operators that QUITE project helped them to gain an understanding of ergonomics. They were able to express the problems they detect and to assess contribution of interventions in handling these problems. Correct work methods manual was deemed helpful to provide them with information they easily could refer. Remainder figure was observed to be helpful in keeping issues pertaining with work posture fresh in daily work environment. Figure also provided a visual model according to which operators could fit their work posture. Ergonomics effort at large was reported to enhance operators' motivation by emphasizing the importance of their occupational health.

It could therefore be claimed that ergonomics interventions resulted in ergonomics improvement both in quantitative and qualitative terms.

IV.5.6. Monitoring quality indicators after interventions

Quality indicators were monitored in collaboration with quality manager of Talu Textile. Quality performance of machine sewing lines was monitored through weekly quality reports which included number of products, types, number and proportion of SORDs and other defects. Proportion of SORDP per batch was extracted from quality data collected via these weekly reports. Ergonomics intervention phase was initiated by ergonomics training early in June. Following interventions were implemented through June, July and August. Thus, quality reports covering 10 weeks after September comprised data for analysis of quality performance after interventions. As emphasized by Shannon *et al*, (1999), data gathering period was kept equal before/after ergonomics intervention. Summary of change in quality indicators after ergonomics interventions was presented in table below.

Table IV.18. Summary of Change in Quality Indicators after Ergonomics Interventions

	BEFORE ERGONOMICS INTERVENTION (April-May 2005, 10 weeks)				AFTER ERGONOMICS INTERVENTION (September-November 2005, 10 weeks)				
Lines	N of batches	N Products	N SORDP	Proportion of SORDP	N of batches	N Products	N SORDP	Proportion of SORDP	Reduction
Line 1	39	18275	1630	**8.9 %**	52	23650	930	**3.9 %**	**56 %**
Line 2	44	30198	1768	**5.85 %**	52	24830	695	**2.8 %**	**52 %**
Total	83	48473	3398	**7.01 %**	104	48480	1625	**3.4 %**	**51 %**

As a mark of accomplishment, results showed that overall proportion of SORDP in both lines was decreased substantially after ergonomics interventions; 56 % and 52 % being in Line 1 and 2 respectively. Total proportion of SORDP was decreased by 51 %. This primary analysis was supplemented with statistical analysis on mean proportion of SORDP per batch. In order to test the difference between before/after means proportion of SORDP, independent samples t-tests were performed on mean proportion of SORDP per patch.

Analysis hypothesis for t-test was structured as below:

μ_0 = Mean proportion of SORDP per batch before ergonomics interventions

μ_1 = Mean proportion of SORDP per batch after ergonomics interventions

$$H_0: \mu_0 = \mu_1 \qquad H_1: \mu_0 > \mu_1$$

Levene's test of equal variances was undertaken prior to t-test (i.e. $\alpha = 0.05$). Results of Levene's test showed that differences between variances of mean proportion of SORDP before/after ergonomics intervention in Line 1, 2 and total batches were not significant (i.e. p: $0.114 > 0.05$, $0.682 > 0.05$ and $0.228 > 0.05$ respectively), which allowed t-test. Results of t-test were given in table below.

Table IV.19. Results of T-Test on Mean Proportion of SORDP after Ergonomics Intervention.

	BEFORE ERGONOMICS INTERVENTION (April-May 2005, 10 weeks)			AFTER ERGONOMICS INTERVENTION (September-November 2005, 10 weeks)			t-test	
Lines	N of batches	Mean SORDP Per batch	Std. Dev.	N of batches	Mean SORDP Per batch	Std. Dev.	t	p
Line 1	39	0.079	0.064	52	0.051	0.05	2.34	0.011
Line 2	44	0.061	0.058	52	0.034	0.061	2.17	0.016
Total	83	0.069	0.062	104	0.042	0.057	3.15	0.001

Results demonstrated that mean SORDP per batch was significantly decreased with p: $0.011 < 0.05$, $0.016 < 0.05$ and $0.001 < 0.05$ for Line 1, 2 and total batches respectively after ergonomics interventions. Thus, null hyphothesis was rejected and results indicated that mean proportion of SORDP per batch after ergonomics interventions was significantly lower than mean proportion of SORDP per batch before ergonomics interventions. This conclusive results marked achievement of fundamental objectives which posited that ergonomics improvements would yield quality improvement.

IV.5.7. Assessment and communication of project outcomes

IV.5.7.1. Assessment of project outcomes

QUITE project targeted to identify ergonomics problems/risks that relate to quality performance in machine sewing task, to undertake ergonomics interventions that address these problems/risks with a quality improvement focus and to monitor change in quality aftermath. It was the first project that integrated ergonomics and quality in Talu Textile and its completion took 9 months. A participatory approach which involved managers, supervisors, maintenance team, quality personnell and sewing operators in planning, administration and assessment of project steps was adopted. Relevant literature was continuously reviewed along with the progression of project and decisions regarding project was supported by academic knowledge. While ergonomics analysis via ERA questionnaire and QEC provided basic knowledge about ergonomics problems/risks existing in machine sewing task, MS discomfort part of ERA questionnaire yielded basic data regarding to occupational health issues for sewing operators. Observational risk analysis by QEC, a recently validated method, was presumably one of the first applications of the QEC in sewing task.

Interventions were planned and undertaken gradually by employing participation mechanisms that prevented resistance to change to a large extent. Sewing operators were continuously interviewed, which facilitated acceptance of and motivation toward interventions. It was observed that operators gained a certain conscious about correct work methods through ergonomics training. Correct work methods manual enhanced motivation of operators to employ ergonomic methods during task. Installation of CWPR figure was also original in that it was a new method to facilitate recall of correct postures. Workstation adjustments targeted to train and to enable operators to adjust their workstations as necessary. Tilting adjustment, a new idea for company, was implemented in stepwise manner and was accepted by operators very positively. Implementation of interventions was successful owing to participatory approach and duly undertakings. Continuous interviews with operators and giving them opportunity to express their opinions not only provided qualitative data supplementary to quantitative data but also became the key factor in this success.

Analysis of both ergonomics issues and change in quality indicators after interventions provided ample evidence that improvement was achieved in both sides. Ergonomics improvement was significant in behavioral change of operators toward adoption of correct work methods and in postural risks which would reduce ergonomics problems and MS discomfort enhancing quality performance in long term. Quality improvement was identified through significant reduction in proportion of SORDP per batch after interventions. It could be concluded that objectives of project were satisfactorily achieved.

IV.5.7.2. Communication of project outcomes

Project outcomes were communicated to CEO of Talu Textile, affected managers in participation group by a written final report in November 2005. The report included summary of interventions, results of replicated ERA questionnaire and QEC after interventions, analysis on changes in quality indicators, recommendations, acknowledgements and references. Duly submission of final report was appreciated. Quality improvement was found notable. Due to request of

CEO of Talu Textile, report was introduced and results of the QUITE application were presented to company managers in a special meeting which made possible collaborative exchange of ideas. Ergonomics interventions were found useful by managers as well and it was proposed to extend ergonomics interventions, especially ergonomics training to other sewing lines and to Adapazarı plant of company within a program. Communication of results provided useful feedback to affected parties about results of the effort and concluded application of QUITE methodology.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

V.1. CONCLUSIONS

Objectives of present dissertation were to elaborate conceptual relationship between ergonomics and quality in manufacturing context, to develop a project-level quality improvement methodology which integrates ergonomics with quality and to carry out application of this methodology in a natural manufacturing environment. Main motivation for this dissertation was requirement of such a methodology for employing ergonomics as a quality improvement tool and paucity of applications which demonstrate concrete, quantified results of integrating these two fundamental concepts of manufacturing. It could be claimed that present study addressed to all three objectives satisfactorily. A broad literature survey was performed to investigate conceptual relationship between ergonomics and quality. Based upon conceptual work on fundamental theories, contemporary approaches, applications and tools of quality improvement and industrial ergonomics, a project level methodology; “Quality Improvement through Ergonomics” (QUITE) was developed. Subsequently QUITE methodology was applied in an apparel manufacturing company. Significant improvements in both ergonomics and quality were attained. Positive outcomes of application not only substantiated applicability and effectiveness of QUITE methodology, but also provided persuasive evidence that quality could be improved through ergonomics practices in manufacturing context.

Review of a vast body of literature including fundamental theories, conceptual research and case studies from both ergonomics and quality areas formed the core of knowledge background for present study. Exploration of conceptual relationship between ergonomics and quality in manufacturing involved not only basic links at micro level such as human error reduction via ergonomics interventions, but also macro level, organizational aspects of this relationship such as role of ergonomics in corporate quality systems.

It was concluded that, ergonomics and quality were supplementary concepts which interact on numerous aspects of labour intensive manufacturing. Ergonomics and quality have human at center, serve corporate goals, require participation, target reduction of human error, deal weightly with fitting work environment to human, adopt continuous improvement philosophy and involve similar analysis tools and methods. Successful integration of ergonomics and quality in manufacturing could culminate in; substantial human error reduction which enhances quality performance, motivation of employees by enhancing occupational safety and health issues, internal/external customer satisfaction and high quality performance. These benefits lead to enhancement of human well-being and achievement of corporate goals in the long run.

Ergonomics and corporate qulity systems interact to a large extent. Several authors have investigated and emphasized essential role of ergonomics in TQM, ISO 9001 and EFQM Business Excellence models which were widely applied to attain high corporate quality performance. Whilst corporate quality systems benefit from use of ergonomics in building a human friendly work environment, fundamental targets of ergonomics could be accomplished via utilization of quality-based processes such as quality circles or certification process. Hence, corporate quality systems serve as an organizational infrastructure to carry out ergonomics improvements.

As an extension of literature review, five case studies which demonstrated implementation of ergonomics interventions for quality improvement purposes were elaborated in a separate section. These case studies provided essential knowledge for development of QUITE methodology by exemplifying how to link ergonomics practices with quality efforts in variety of manufacturing environments. Significant improvements obtained in these case studies showed promise for applicability and effectiveness of QUITE methodology.

QUITE methodology was based upon exploration and synthesis of theory, applications and tools of ergonomics, quality improvement, quality management and corporate ergonomics programs. It involved extensive use of not only analysis and intervention methods/tools of ergonomics and quality but also contemporary approaches in both quality and ergonomics concepts such as participatory ergonomics.

QUITE methodology is unique in many respects. Key organizational factors that lead to success in project implementation (e.g. management commitment, participation, communication) were addressed through phases of QUITE methodology. Planning, analysis and intervention phases were explicitly described. Parcipatory and macro ergonomics approaches were adopted as well as technical ergonomics intervention methods. As emphasized in section III.3, participation, communication and training were three indispensable components of ergonomics and quality projects. QUITE methodology centered on these issues as well; while participation and communication were included early in planning phase and were further required to be maintained throughout analysis and intervention phases, training was dedicated a step within intervention phase. QUITE is unique in that communication was allocated an action step due to its utmost importance. Communication of intermadiate project outcomes to affected members of organization and participation groups was deemed necessary to sustain support and motivation toward QUITE project. Those anticipated benefits were realized and participation and communication played an essential role in application part.

QUITE methodology included selection and design of ergonomics analysis tools due to the fact that analysis tools should fit not only specific project objectives, but also characteristics of manufacturing process, environment and participants. In this respect QUITE methodology allowed using custom-tailored analysis tools that would meet particular demands of project, as well as use of standard methods. While ERA questionnaire was devised to analyse ergonomics problems in machine sewing task via subjective reporting of low-educated sewing operators, a standard observational/subjective risk assessment tool, QEC was used to complement analysis. Quality analysis tools; Pareto analysis and Cause-and- Effect diagram were also used to relate ergonomics analysis with quality aspect of project.

QUITE methodology enticed concentration on intervention planning. Number of studies mentioned in literature review has proved that ergonomics training served multiple purposes; to equip people with necessary ergonomics knowledge, to stimulate participation and creativity and to advance interventions beyond common sense. Hence, ergonomics training was one of the key parts in intervention process. Ergonomics training given to sewing operators sufficed to serve these purposes successfully. Since QUITE methodology was constructed as before-after analysis, ergonomics problems/risks and quality indicators were monitored before and after ergonomics interventions. QUITE methodology provided a robust action plan which adressed to human labour intensive manufacturing contexts with a quality system.

Application of QUITE methodology was carried out in Talu Textile, an apparel manufacturing company. Selection of textile industry contributed to originality of present study in that a relevant application in textile industry was not found within literature survey. Besides, ergonomics is extensively needed in textile industry, especially in machine sewing task, on which present research was focused. Talu Textile thoroughly satisfied prerequisite conditions for application of QUITE methodology. First; it heavily involved human labour in core manufacturing processes. Second; being an ISO 9001:2000 certified company, Talu Textile had an active qualiy system which was administered by quality department. Third; beginning with CEO of company, Talu Textile had an improvement-focused organizational environment. Owing to high educational profile of managers, majority of them being industrial engineers, a profound respect and interest for QUITE application prevailed in company, which substantially facilitated progression of project stages.

QUITE methodology was applied in machine sewing department. Ergonomics risks/problems identified via ERA questionnaire and QEC were; static and awkward work postures, lack of training and ergonomics knowledge, visual demand, work pace, long work hours and discomfort caused by environmental factors. MS discomfort at upper extremities; neck, shoulders, legs, upper and lower back were prevalent. In order to prioritize discomfort across body areas Pareto analysis was conducted on reported MS discomfort and discomfort at neck/back resulted to be of highest priority. According to QEC results, MS risk exposure level was “Very High” for neck, “High” for back and shoulder/arm and “Moderate” for wrist/arm. It was observed that machine sewing task in question introduced generic ergonomics risks/problems in congruence with literature. Continuous observations and interviews contributed to reveal intensity of identified ergonomics risks/problems. Quantitative data extracted in analysis was supplemented by qualitative data in order to assess prevalence of and changes in ergonomics risks/problems thoroughly, to relate ergonomics problems with quality deficiencies and to assess overall outcomes of QUITE project.

In order to explore causal relationship between ergonomics risks/problems and occurrence of SORD, a Cause-and-Effect diagram was built by contributions of operators and participatory group. Ergonomics risks which were postulated to cause qualiy deficiencies and demonstrated in this diagram were congruent with those identified via ERA questionnaire and QEC; lack of ergonomics training, incorrect work methods and workstation problems, adverse psychosocial and environmental factors.

Ergonomics risks/problems were addressed via gradual implementation of various low-cost interventions; ergonomics training, introduction of correct work methods manual to sewing operators, installation of correct work posture figure on machines, tilting sewing machines and several workstation adjustments. Interventions were planned and implemented based upon scientific research and organizational considerations. Continuous and incremental change approach was adopted instead of making drastic changes in a short period. Prior to implementation, interventions were discussed and agreed upon with affected parties (i.e. CEO, managers, line supervisors, maintenance team) from applicability and operator acceptance standpoints. Completion of whole set of interventions took longer than two months. Operator acceptance toward interventions was enhanced via participatory practices such as frequent informal interviews with operators or trial applications which enabled participants to express their opinions. Participatory approach, effective communication, well-grounded progression of QUITE methodology and duly completion of steps resulted in accomplishment of interventions.

Ergonomics interventions had certain influence on exposure to ergonomics risks/problems. ERA questionnaire and QEC was replicated after interventions. Results of ERA questionnarie showed (i.e. at 0.05 significance level) substantially significant reductions in frequency of exposure to ergonomics risks; bending upper body, bending neck, bending wrists and leaning arms on sharp edges, which were prevalent awkward postures leading to MS discomfort with p values of 0.000, 0.0023, 0.000 and 0.038 respectively.

According to results of QEC, MS risk levels in neck, back, shoulder/arm and wrist/hands were significantly reduced at 0.05 significance level with *p* values of 0.003, 0.000, 0.004 and 0.000 respectively, which indicated that operators adopted ergonomically improved work lower than before intervention period. Interventions were deemed effective in changing prevalent behaviors basically by giving operators a consciousness about correct work practices (e.g. importance of maintaining correct work posture, necessity of workstation adjustments). Majority of operators reported to have found interventions useful, which indicated satisfactory acceptance toward interventions.

Changes in quality indicators were evaluated through statistically testing difference between proportions of SORDP per batch before/after ergonomics interventions. Quality data of 10 weeks before/after interventions was used for evaluation. Results showed that proportion of SORDP decreased from 8.9 % to 3.9 % in Line 1, from 5.85 % to 2.8 % in Line 2 and from 7.01 % to 3.4 % in total after ergonomics interventions. These results indicated reductions in proportion SORDP by 56 % and 52 % in Line 1 and Line 2 respectively and by 51 % totally. Further independent samples t-tests (i.e. at 0.05 significance level) showed that, mean SORDP per batch was significantly reduced with *p* values: 0.011, 0.016 and 0.001 in Line 1, Line 2 and in total after ergonomics interventions.

This conclusive results pointed to a remarkable improvement in quality performance, which indicated that fundamental objectives of present study were achieved.

V.2. RECOMMENDATIONS AND FUTUREWORK

Present study involved certain limitations. QUITE Methodology was applied in natural apparel manufacturing environment (i.e. machine sewing task) which constrained number of participants. Ergonomics analysis using ERA questionnaire and QEC was applied with statistically adequate but limited number of participants. For general validity of methods, applications should be carried out with larger sample groups.

Given the basic objective was quality improvement, applicable interventions were carried out as a set and effect of each ergonomics intervention was not evaluated separately. In order to construct mathematical model of relationship between ergonomics and quality, effect of ergonomic variables on quality performance should be quantified. A positive linear relation could be proposed to exist between ergonomics and corporate quality performance. Further employment of advanced mathematical methods such as fuzzy logic would be useful to explore and to attain general validity of relationship between ergonomics and quality in manufacturing.

In addition to demonstrating positive effect of ergonomics on quality performance, present study introduced important recommendations pertaining with organizational aspects of ergonomics applications and directions for implications for future research.

It was revealed that beside technical proficiency, effective and well-planned communication was of utmost importance for ergonomics projects. Duly reporting to managers, transparency, impartiality and dedicating time and effort to reach a consensus between affected parties about pace of project were influencial communication practices within QUITE application. CEO of Talu Textile was informed about all stages and was presented written reports at the end of planning and analysis phases. Results of ergonomics analysis before/after interventions and evaluation of quality indicators were explicitly documented in reports. These reports served to substantiate dedication of author to project, to convince company members about academic value of project. Progression of project was discussed with participation group before presentation to CEO, which comforted managers about project, facilitated decision making toward applications, helped to integrate QUITE project with company structure.

Communication with operators was deemed crucial for successful implementation of interventions. Technical material (i.e. correct work methods manual) was designed in compliance with technical communication principles in order to fit information content to low education level of operators. Use of academic terminology was avoided during casual communication in order to assure understandability. This approach substantially contributed to understandability of interventions and achievement of behavioral change toward correct work practices. These positive outcomes substantiated benefit of dedicating an action step for communication planning within planning phase of QUITE methodology. It is recommended that, communication should be well-planned and considered throughout not only further QUITE applications but also ergonomics undertakings.

Participation was another organizational key issue in QUITE application. As was the case with communication, participation was dedicated an action step in planning phase of methodology. Members of participation group were identified at early stages of project. Mid-managers, department and line supervisors, maintenance team and operators formed participation group. Participation group was consulted for decision making, selection of task and quality indicator, planning of analysis and interventions, assessment of outcomes. Maintenance team substantially contributed to workstation adjustments and tilting application. It was observed that participatory practices such as managing pilot tilting application and involving operators in progression of project facilitated interventions. Participation in QUITE application contributed to self-confidence of operators and provided them with a certain degree of control over their work life. Effective and dynamic participation was maintained in parallel with communication practices throughout QUITE application. Thus, it was strongly recommended that, participation should be given high priority as an inherent part of organizational ergonomics applications.

Conceptual structure, methodology and application of present study highlighted variety of directions for future research.

Although present study yielded in quality improvement results through ergonomics interventions, further research was required for general validity of findings. Applications of QUITE methodology should be expanded to larger participant groups and to various manufacturing tasks. Quantification and mathematical modeling of relationship between ergonomics and quality in organizations should be investigated using advanced mathematical methods such as fuzzy logic.

Among number of labour intensive tasks in manufacturing flow in company, QUITE methology was applied solely in machine sewing task. With a broader approach, enlarging QUITE application to corporate level by employing ergonomics for quality improvement in multiple tasks concurrently allow monitoring change in multiple quality indicators and would increase impact of ergonomics on corporate quality performance. This extended approach could enrich concept of QUITE methodology.

QUITE Methodology was developed particularly for manufacturing industry. It was considered that ergonomics practices could improve human performance related quality level in service industry by reducing operational human error and optimizing workload (Karapetrovic, 1999). Hence, methodology introduced in present study can be adopted for and applied in service context.

Application of QUITE methodology was carried out in textile manufacturing environment. In further stages, extending QUITE application to different manufacturing industries which satisfy prerequisite conditions of methodology could enhance validity of methodology and contribute to quality improvement concept for those industries. Thus, application of QUITE project in various manufacturing is another research direction.

Role of ergonomics in three corporate quality systems; TQM, ISO 9001:2000 and EFQM Business Excellence Model was elaborated within conceptual research part of present study. Continuous evolvement of quality introduces new quality systems and models such as Six Sigma or Total Productive Maintenance. Given the strong link between ergonomics and quality in manufacturing, role of ergonomics in new and different quality systems would contribute to relevant breadth of literature.

Computer network systems and computer based communication mediums such as intranets are extensively utilized in information infrastructure of modern organizations. It is considered that, utilization of network systems for QUITE application would not only facilitate participation and communication, but also would make computer-based ergonomics training, quality monitoring and reporting possible. Integrated application of QUITE methodology with a computer based systems could culminate in considerable developments for applied ergonomics literature.

Present study introduced vast literature review on relationship between ergonomics and quality. Subsequently, QUITE; a new, clear-cut methodology to employ ergonomics for quality improvement in manufacturing environment was developed. Finally, QUITE methodology was validated through an application in which ergonomics practices contributed to quality performance in machine sewing task via human error reduction.

As a corollary, it is considered that broad literature survey and profound conceptual research, development and application of QUITE methodology, outcomes of application recommendations and directions for future research presented in this study would contribute to literature and would shed light to future researches in ergonomics and quality subject areas.

REFERENCES

Aborg C.; Fernström E.; Ericson M.O.: "Work content and satisfaction before and after a reorganization of data entry work", *Applied Ergonomics*, 29 **(1998)** 473-480.

Adam E.; Foster S.T.: "Quality improvement approach and performance: multisite analysis within a firm", *Journal of Quality Management,* 5 **(2000)** 143-158.

Annett J.: "Subjective rating scales: Science or art?", *Ergonomics,* 45 **(2002)** 966-987.

Alexandre N.M.C.; Moraes M.A.A.; Filho H.R.C.; Jorge S.A.: "Evaluation of a program to reduce back pain in nursing personnel", *Rev Saude Pubblica*, 35 **(2001)** 356-361.

Axelsson J.: "Quality and ergonomics management: Toward an emerging integrated paradigm", *Proceedings of the Human Factors and Ergonomics Society 44th Annual Meeting,* San Diego, California, USA, July 30-August 4, 2 **(2000)** 467- 470.

Bagnara S.; Stortone C.; Fontana A.; Micheli S.; Nicoletti R.: "Participative work design: A case study", In *Advances in applied ergonomics*, Proceedings of the 1st International Conference on Applied Ergonomics (ICAE'96), Istanbul, Turkey, May 21-24, **(1996)**; Özok A.F.; Salvendy G. Eds.; USA Publishing, West Lafayette, Indiana, USA **(1996)** 195-198.

Barros E.N.C.; Alexandre N.M.C.: "Cross-cultural adaptation of the Nordic musculoskeletal questionnaire", *International Nursing Review*, 50 **(2003)** 101-108.

Bezjak Z.; Knez B.: "Workplace design and loadings in the process of sewing garments", *International Journal of Clothing*, 7 **(1995)** 89-101.

Björksten M.G.; Boquist B.; Talback M.; Edling C.: "The validity of reported musculoskeletal problems. A study of questionnaire answers in relation to diagnosed disorders and perception of pain", *Applied Ergonomics*, 30 **(1999)** 325-330.

Blader S.; Holst U.B.; Danielsson S.; Ferhm E.; Kalpamaa M.; Leijon M.; Lindh M., Markhede G.: "Neck and shoulder complaints among sewing-machine operators", *Applied Ergonomics,* 22 **(1991)** 251-257.

Blome M.; Johansson C.R.; Odendrick P.: "Computer supported visualisation of quality systems developed by network teams", *Applied Ergonomics,* 34 **(2003)** 239-247.

Bozkurt R.; Incir G.; Peskircioglu N.; Batuk N.: "The contributions of the total quality activities on the improvements of the ergonomic conditions of the organizations", *Proceedings of 5th Ergonomics Congress*, ITU, Istanbul, Turkey, November 15-17, **(1995)** 65 – 79.

Brodie D.; Wells R.: "An evaluation of the utility of three ergonomics checklists for predicting health outcomes in a car manufacturing environment", *Proceedings of the 29th Annual Conference of Human Factors Association of Canada*, Winnipeg, Canada, September 13-17, **(1997)** 45- 52.

Bryns G.; Agnew J.; Curbow B.: "Attributions, stress and work related low back pain", *Applied Occupational and Environmental Hygiene*, 17 **(2002)** 752-764.

Buckle P.W.; Devereux J.J.: "The nature of work-related neck and upper limb muculoskeletal disorders", *Applied Ergonomics,* 33 **(2002)** 207-217.

Butler M.P.: "Corporate ergonomics programme at Scottish & Newcastle", *Applied Ergonomics,* 34 **(2003)** 35-38.

Chan J.; Janowitz I.; Lashuay N.; Stern A.; Fong K.; Harrison R.: "Preventing musculoskeletal disorders in garment workers: Preliminary results regarding ergonomics risk factors and proposed interventions among sewing machine operators in the San Fransisco bay area", *Applied Occupational and Environmental Hygiene,* 17 **(2002)** 247-253.

Charlton S.G.: "Questionnaire techniques for test and evaluation", In *Handbook of Human Factors Testing and Evaluation*, 1st Ed.; O'brien T.G.; Charlton S.G.: Eds.; Lawrence Erlbaum Associates, Inc., Mahwah New Jersey, USA **(1996)** 81-101.

Conrads J.A.: "Illustruction: Increasing safety and reducing liability exposure", *IEEE Transactions on Professional Communication*, 30 **(1987)** 133-135.

Cornell University Ergonomics Web, Cornell Musculoskeletal Discomfort Questionnaires**,** (1999) http://ergo.human.cornell.edu **(Access date:** 2001**).**

Das B.; Sengupta A.K.: "Industrial workstation design: a systematic ergonomics approach", *Applied Ergonomics*, 27 **(1996)** 157-163.

David G.; Woods V.; Buckle P.: "Further development of the usability and validity of the Quick Exposure Check (QEC)", *Research Report* 211, Robens Cente for Health Ergonomics, University of Surrey, Guilford **(2005)**.

Deming W.E.: "Out of crisis", Massachusetts Institute of Technology, USA **(1986)**.

Delleman N.J.; Dul J.: "Sewing machine operation: workstation adjustment, working posture, and workers' perceptions", *International Journal of Industrial Ergonomics,* 30 **(2002)** 341-353.

Devore J.L.: "Probability and statistics for engineering and the sciences", 4th Ed.; Brooks/Cole Publishing Company, CA, USA **(1995)**.

Dickinson C.E.; Campion K.; Foster A.F.; Newman S.J.; O'Rourke A.M.T.; Thomas P.G.: "Questionnaire development: An examination of the Nordic Musculoskeletal Questionnaire", *Applied Ergonomics*, 23 **(1992)** 197-201.

Douglas M.S.; Grout J.R.: "The human side of mistake-proofing", *Production and Operations Management.,* 10 **(2001)** 440- 459.

Drury C.G.: "Human factors and quality: Integration and new directions", *Human Factors and Ergonomics in Manufacturing,* 10 **(2000a)** 45-59.

Drury C.G.: "Global quality: Linking ergonomics and production", *International Journal of Production Research,* 38 **(2000b)** 4007-4018.

Drury C.G.; Broderick R.L.; Weidman C.H.; Mozrall J.L.R.: "A corporate-wide ergonomics programme: implementation and evaluation", *Ergonomics*, 42 **(1999)** 208-228.

Drury C.G.: "Ergonomics and the quality movement", *Ergonomics,* 40 **(1997)** 249-264.

EFQM (European Foundation for Quality Management) Official Web Site: "EFQM: Fundamental Concepts", **(1999-2003)** http://www.efqm.org (Access date: **2003**).

Eklund J.: "Quality as prevention of musculoskeletal disorders", *Proceedings of the Human Factors and Ergonomics Society 44th Annual Meeting,* San Diego, California, USA, July 30-August 4, 5 **(2000)** 497-451.

Eklund J. A. E.: "Ergonomics, quality and continuous improvement conceptual and empirical relationships in an industrial context", *Ergonomics*, 40 **(1997)** 982-100.

Eklund J. A. E.: "Relationship between ergonomics and quality in assembly work", *Applied Ergonomics*, 26 **(1995)** 15-20.

Ellegast R.P.; Herda C.A.: "Ergonomic intervention at sewing industry workplaces", In *Contemporary Ergonomics,* Proceedings of Annual Conference of the Ergonomics Society (EAC'2004), Swansea, Wales, April 4-6, **(2004);** McCabe P.; Ed.; CRC Press Florida, USA **(2004)** 230-234.

Feigenbaum A. V.: "Total quality control", 3rd Ed.; McGraw Hill Inc., USA, **(1991)**.

Genaidy A.M.; Al-Shedi A.A.; Karwowski W.: "Postural stress analysis in industry", *Applied Ergonomics*, 25 **(1994)** 77-87.

George C.; Cooper F.; Douglas A.: "Implementing the EFQM excellence model in a local authority", *Managerial Auditing Journal*, 18 **(2003)** 122-127.

Gleason J.; Wackerman J.P.: "Manual dexterity: What makes instructional manuals usable", *IEEE Transactions on Professional Communication*, 27 **(1984)** 59-61.

Gonzalez B. A.; Adenso-Diaz B.; Torre P. G.: “Ergonomic performance and quality relationship: an empirical evidence case”, *International Journal of Industrial Ergonomics*, 31 **(2003)** 33-40.

Govindaraju M.; Pennathur A.; Mital A.: “Quality improvement in manufacturing through human performance enhancement”, *Integrated Manufacturing Systems,* 12 **(2001)** 360 -367.

Hagg G.M.: “Corporate initiatives in ergonomics: An introduction”, *Applied Ergonomics*, 34 **(2003)** 3-15.

Halpern C.A.; Dawson K.D.: “Design and implementation of a participatory ergonomics program for machine sewing tasks”, *International Journal of Industrial Ergonomics*, 20 **(1997)** 429-440.

Hartley J.: “Eighty ways of improving instructional text”, *IEEE Transactions on Professional Communication*, 24 **(1981)** 17-27.

Helander M.G.: “The Human Factors Profession”, In *Handbook of Human Factors and Ergonomics*, 2nd Ed.; Salvendy G., Ed.; John Wiley & Sons, New York, USA **(1997)** 3-17.

Helander M.G.; Burri G.J.: “Cost effectiveness of ergonomics and quality improvements in electronics manufacturing”, *International Journal of Industrial Ergonomics,* 15 **(1995)** 137-151.

Hendrick H.W.: “Determining the cost-benefits of ergonomics projects and factors that lead to their success”, *Applied Ergonomics*, 34 **(2003)** 15-20.

Hendrick H.W.: “Good ergonomics is good economics”, www.hfes.org **(1996)** (Access date: **2002**).

Hendrick H. W.: “Ergonomics in organizational design and management”, *Ergonomics*, 34 **(1991)** 743-756.

Herbert R.; Dropkin J.; Warren N.; Sivin D.; Doucette J.; Kellogg L.; Bardin J.; Kass D.; Zoloth S.: “Impact of a joint labor-management ergonomics program on upper extremity musculoskeletal symptoms among garment workers”, *Applied Ergonomics,* 32 **(2001)** 456-460.

Hignett S.; Mcatamney L.: “Rapid Entire Body Assessment (REBA)”, *Applied Ergonomics,* 31 **(2000)** 201-205.

Hilderbrandt V.H.; Bongers P.M.; Van Duk F.J.H.; Kemper H.C.G.; Dul J.: “Dutch musculoskeletal questionnaire: Description and basic qualities”, *Ergonomics,* 44 **(2001)** 1038-1055.

Jones R.J.: “Corporate ergonomics program of a large poultry processor”, *American Industrial Hygiene Association Journal,* 58 **(1997)** 132-137.

Jordan P.W.: “Human factors for pleasure in product use”, *Applied Ergonomics,* 29 **(1998)** 25-33.

Joseph B.S.: “Corporate ergonomics programme at Ford Motor Company”, *Applied Ergonomics,* 34 **(2003)** 23-28.

Juran J.M.; Gryna F.M.: “Quality planning and analysis”, 3rd Ed., McGraw Hill Inc., Singapore, **(1993).**

Juran J.M.: “The quality function” In *Quality Control Handbook*, 4th Ed.; Juran J.M., Gryna F.M., Eds.; McGraw Hill Inc., USA, **(1988).**

Karapetrovic S.: “ISO 9000, service quality and ergonomics”, *Managing Service Quality,* 9 **(1999)** 81-89.

Karhu O.; Kansi P.; Kuorinka I.: “Correcting working postures in industry: A practical method for analysis”, *Applied Ergonomics*, 8 **(1977)** 199-201.

Karltun J.: “Change processes and ergonomic improvements in small and medium enterprises”, *Human Factors and Ergonomics in Manufacturing,* 14 **(2004)** 135-155.

Karltun J.; Axelsson J.; Eklund J.: “Working conditions and effects of ISO 9000 in six furniture-making companies: Implementation and processes”, *Applied Ergonomics*, 29 **(1998)** 225-232.

Kawecka-Endler A.: “Modern trends formation of quality in assembling”, In *Advances in applied ergonomics*, Proceedings of the 1st International Conference on Applied Ergonomics (ICAE’96), Istanbul, Turkey, May 21-24, **(1996)**; Özok A.F.; Salvendy G. Eds.; USA Publishing, West Lafayette, Indiana, USA **(1996)** 859-862.

Kelly M.J.; Ortiz D.J.: “Ergonomic challenges in conventional and advanced apparel manufacturing”, *Final report,* George Tech Project, A-8311 Georgia Institute of Technology, Georgia Tech Research Institute, Environmental Science and Technology Laboratory, Electronic Systems Laboratory **(1992).**

Keyserling W.M.; Stetson D.S.; Silverstein B.A.; Brouwer M.L.: “A checklist for evaluating ergonomic risk factors associated with upper extremity cumulative trauma disorders”, *Ergonomics,* 36 **(1993)** 807-831.

Keyserling W.M.; Armstrong T.J.; Punnett L.: “Ergonomic job analysis: A structured approach for identifying risk factors associated with overexertion injuries and disorders”, *Applied Occupational and Environmental Hygiene,* 6 **(1991)** 353-363.

Kim Y.S.; Cochran D.S.: “Reviewing TRIZ from the perspective of axiomatic design”, *Journal of Engineering Design*, 11 **(2000)** 79-94.

Kivi P.; Mattila M.: “Analysis and improvement of work postures in the building industry: Application of the computerized OWAS method”, *Applied Ergonomics*, 22 **(1991)** 43-48.

Klatte T.; Daetz W.; Laurig W.: “Quality improvement through capable processes and ergonomic design”, *International Journal of Industrial Ergonomics,* 20 **(1997)** 399-411.

Kohn J.P.; Friend M.A.: “Quality and ergonomics: The team approach to the occupational people factor”, *Professional Safety,* 38 **(1993)** 39-42.

Konz S.A.: “Environmental Design”, In *Handbook of Industrial Engineering*, Salvendy G., Ed., John Wiley & Sons, New York, USA **(1992)** 1047- 1077.

Kovanı A.: “The motivation factor in the application of the Total Quality Management (TQM) Philosophy”, *Proceedings of 5th Ergonomics Congress*, ITU, Istanbul, Turkey, November 15-17, **(1995)** 655 – 662.

Kuorinka I.: “Tool and means of implementing participatory ergonomics”, *International Journal of Industrial Ergonomics,* 19 **(1997)** 267-270.

Kuorinka I.; Patry L.: “Participation as a means of promoting occupational health”, *International Journal of Industrial Ergonomics*, 15 **(1995)** 365-370.

Kuorinka I.; Jonsson B.; Kilbom A.; Vinterberg H., Biering-Sorensen F.; Anderson G.; Jorgensen K.: “Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms”, *Applied Ergonomics*, 18 **(1987)** 233-237.

Labar G.: “Can ergonomics cure ‘human error’?”, *Occupational Hazards,* 58 **(1996)** 48- 51.

Leon N.: “Putting TRIZ into product design”, *Design Management Journal,* 14 **(2003)** 58-65.

Lewandowski J.: “Ergonomics in total quality management”, *Proceedings of the Human Factors and Ergonomics Society 44th Annual Meeting,* San Diego, California, USA, July 30-August 4, 5 **(2000)** 284-287.

Li G.; Buckle P.: “Current techniques for assessing physical exposure to work-related musculoskeletal risks, with emphasis on posture-based methods”, *Ergonomics,* 42 **(1999a)** 674-695.

Li G.; Buckle P.: “Evaluating change in exposure to risk for musculoskeletal disorders – a practical tool”, *Research Report* 211, Robens Cente for Health Ergonomics, University of Surrey, Guilford **(1999b)**.

Li G.; Buckle P.: “A practical method for the assessment of work-related musculoskeletal risks-Quick Exposure Check (QEC)”, *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting, Chicago, Illinois,* USA, October 5-9, **(1998)** 1351-1355.

Li G.; Haslegrave C.M.; Corlett E.N.: “Factors affecting posture for machine sewing tasks”, *Applied Ergonomics,* 26 **(1995)** 35-46.

Lin L.; Drury C.G.; Kim S.W.: "Ergonomics and quality in paced assembly lines", *Human Factors and Ergonomics in Manufacturing,* 11 **(2001)** 377–382.

Macleod D.: "The ergonomics edge: Improving safety, quality and productivity", 1st Ed.; Van Nostrand Reinhold, New York, USA **(1995)**.

Manuele F. A.: "How do safety, ergonomics and quality maangement interface?", *Industrial Management*, 36 **(1994)** 4-6.

Massaccesi M.; Pagnotta A.; Soccetti A.; Masali M.; Masiero C.; Greco F.: "Investigation of work-related disorders in truck drivers using RULA method", *Applied Ergonomics,* 34 **(2003)** 303-307.

Matias J.C.O.; Coelho D.A.; "The integration of systems of quality management, environmental management and occupational health and safety management", *International Journal of Production Research*, 40 **(2002)** 3857-3866.

Mcatamney L.; Corlett E.N.: "RULA: A survey method for the investigation of work-related upper limb disorders", *Applied Ergonomics,* 24 **(1993)** 91-99.

Megaw E.D.: "Factors affecting visual inspection accuracy", *Applied Ergonomics,* 10 **(1979)** 27-32.

Medsker G.J.; Campion M.A.: "Job and team design", In *Handbook of Human Factors and Ergonomics*, 2nd Ed.; Salvendy G., Ed.; John Wiley & Sons, New York, USA **(1997)** 450-489.

Moreau M.: "Corporate ergonomics programme at automobiles Peugeot-Sochaux", *Applied Ergonomics*, 34 **(2003)** 29-34.

Naderi B.; Baggerman M.: "The result of ergonomics at the forefront in manufacturing: Quality", *Industrial Engineering,* 24 **(1992)** 42-46.

Nagamachi M.: "Requisites and practices of participatory ergonomics", *International Journal of Industrial Ergonomics,* 15 **(1995)** 371-377.

Nicholson A.S.; McNeice B.: "The identification, assessment and impact of 'good ergonomics practices' for casual apparel manufacturing within Levi Strauss Europe, Middle East and Africa", *Proceedings of the Human Factors and Ergonomics Society 44th Annual Meeting,* San Diego, California, USA, July 30-August 4, **(2000)** 146 - 149.

Noro K.: "Concept, methods and philosophy", In *Participatory Ergonomics,*1st Ed.; Noro K.; Imada A.S.: Eds.; Taylor and Francis, London, England **(1991).**

Onur A.; Özok A.F.: "An ergonomic application model in industry", *Proceedings of 5th Ergonomics Congress*, ITU, Istanbul, Turkey, November 15-17, **(1995)** 485- 494.

OSHA (Occupational Safety and Health Administration) Official Web Site: "Sewing and related procedures: Ergonomics", http://www.osha.gov (Access date: **2003**).

Ostry A.S.; Marion S.A.; Demers P.A.; Hershler R.; Kelly S.; Teschke K.; Hertzman C.: "Measuring psychological job strain with the job content questionnaire using experienced job evaluators", *American Journal of Industrial Medicine,* 39 **(2001)** 397-401.

Özok A.F.; Ugurel C.; Unsal S.: "The role of ergonomics in developing a company culture", In *Advances in applied ergonomics*, Proceedings of the 1st International Conference on Applied Ergonomics (ICAE'96), Istanbul, Turkey, May 21-24, **(1996)**; Özok A.F.; Salvendy G. Eds.; USA Publishing, West Lafayette, Indiana, USA **(1996)** 191-194.

Öztürk N.; Babalık F.; Öztürk F.: "Effects of ergonomic improvements on the Total Quality Management for the manufacturers located in Bursa", *Proceedings of 5th Ergonomics Congress*, ITU, Istanbul, Turkey, November 15-17, **(1995)** 90 – 99.

Park K.S.: "Human Error", In *Handbook of Human Factors and Ergonomics*, 2nd Ed.; Salvendy G., Ed.; John Wiley & Sons, New York, USA **(1997)** 151- 173.

Perez N.S.; Anda C.M.: "Musculoskeletal disorders among male sewing machine operators in shoemaking", *Ergonomics,* 36 **(1993)** 793-800.

Pipinich R.E.; Getty R.L.; Abbot W.L.: "Ergonomics: A high priority at Lockhead Fort Worth facility", *Industrial Engineering,* 25 **(1993)** 20-23.

Pun J.C.; Burgel B.J., Chan J.; Lashuay N.: "Education of garment workers: Prevention of work related musculoskelatal disorders", *AAOHN Journal* 52 **(2004)** 338-343.

QCB (Quality Certification Bureau, Inc.), "Overview of ISO 9001:2000", www.qcbinc.com (Access date: **2001).**

Quintana R.; Alonso J.A.: "Ergonomics evaluation of equipment adjustability for Mexican-American population", *Occupational Ergonomics,* 3 **(2002/2003)** 65-80.

Quintana R.: "A methodology for the analysis and prediction of back injuries in apparel manufacturing", *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting,* Albuquerque, New Mexico, USA, September 22-26, **(1997)** 844-848.

Rhijin G.; Tuinzaad B.; Van Deursen J.: "Design of asembly flow and human centred workplaces in Dutch assembly companies", *Proceedings of International Conference on TQM and Human Factors*, Sweden, June 15-17 **(1999)**. www.gfah.de (Access date: **2001**)

Roger W.A.; Lamson N.; Rousseau G.K.: "Warning research: An integrative perspective", *Human Factors, 42* **(2000)** 102-139.

Rooney J.J.; Vanden L.N.V.; Lorenzo D.K.: "Reduce human error", *Quality Progress,* 35 **(2002)** 27- 36.

Sandbrook M.: “Using the EFQM model as a framework for improvement and change”, *Journal of Change Management*, 2 **(2001)** 83-90.

Schwind G.: “When workers hurt, quality suffers”, *Material Handling Engineering,* 51 **(1996)** 51-54.

Shannon H.S.; Robson L.S.; Guastello S.J.: “Methodological criteria for evaluating occupational safety intervention research”, *Safety Science,* 31 **(1999)** 161-179.

Skepper N.; Straker L.; Pollock C.: “A case study of the use of ergonomics information in a heavy engineering design process”, *International Journal of Industrial Ergonomics,*26 **(2000)** 425-435.

Smith R.T.: “Growing an ergonomics culture in manufacturing”, *Proceedings of the Institution of Mechanical Engineers,* 217 **(2003)** 1027- 1030.

Smyth J.: “Corporate ergonomics programme at BCM Airdrie”, *Applied Ergonomics,* 34 **(2003)** 39-43.

Spielholz P.; Silverstein B.; Morgan M.; Checkoway H.; Kaufman J.: “Comparison of self-report, video observation and direct measurement methods for upper extremity musculoskeletal disorder physical risk factors”, *Ergonomics,* 44 **(2001)** 588-613.

Sullivan M.A.; Corlett E.N.: “Transferring ergonomics: A methodology for self diagnosis of workplace problems”, *Occupational Ergonomics,* 1 **(1998)** 223-237.

Taveira A.D.; James C.A.; Karsh B.; Sainfort F.: “Quality management and the work environment: An empirical investigation in a public sector organization”, *Applied Ergonomics* 34 **(2003)** 281–291.

Ulfsfalt U.M.; Falck A.; Forsberg A.; Dahlin C.; Eriksson A.: “Corporate ergonomics programme at Volvo Car Corporation”, *Applied Ergonomics*, 34 **(2003)** 17-22.

Vainio P.; Mattila M.: “Development of a safety and egonomics oriented total quality system for an electricity company”, In *Advances in applied ergonomics*, Proceedings of the 1st International Conference on Applied Ergonomics (ICAE’96), Istanbul, Turkey, May 21-24, **(1996)**; Özok A.F.; Salvendy G. Eds.; USA Publishing, West Lafayette, Indiana, USA **(1996)** 43-46.

Vayvay O.; Erdinc O.: “Dimensions of the relationship between ergonomics and quality in manufacturing: A review”, *In Proceedings of Operations Research/Industrial Engineering Congress*, Gaziantep-Cukurova University, Gaziantep-Adana, Turkey, June 15-18, **(2004a)** 404-406.

Vayvay O.; Erdinc O.: “Interaction of ergonomics and ISO 9001:2000 quality management system in manufacturing”, *In Proceedings of Symposium on Intelligent Manufacturing Systems (IMS’2004)*, Sakarya University, Sakarya, Turkey, September 6-8, **(2004b)** 339-347.

Vezina N.; Tierney D.; Messing K.: "When is light work heavy? Components of the physical workload of sewing machine operators working at piecework rates", *Applied Ergonomics*, 41 **(1992)** 268-276.

Vink P.; Peeters M.; Grundeman R.W.M.; Smulders P.G.W.; Kompier M.A.J.; Dul J.: "A participatory ergonomics approach to reduce mental and physical workload", *International Journal of Industrial Ergonomics,* 15 **(1995)** 389-396.

Wadsworth H.M.; Stephens K.S.; Godfrey A.B.: "Modern methods for quality control and improvement", John Wiley & Sons, Inc. New York, USA **(2002)** 15-124.

Wartenberg C.; Dukic T.; Falck A.; Hallbeck S.: "The effect of assembly tolerance on performance of a tape application task: A pilot study", *International Journal of Industrial Ergonomics,* 33 **(2004)** 369-379.

Webb A.: "TRIZ: An inventive approach to invention", *Engineering Management Journal*, June **(2002)** 117-124.

Wilson J. R.; Haines H. M.: "Participatory ergonomics", In *Handbook of Human Factors and Ergonomics*, 2nd Ed.; Salvendy G., Ed.; John Wiley & Sons, New York, USA **(1997)** 490- 513.

Wong C.Y.; Dahlgaard J.J.: "Towards continuous improvement: A case of self-assessment using the EFQM excellence model", http://www.cip.dk (Access date: **2003**).

Wright P.: "Five skills technical writers need", *IEEE Transactions on Professional Communication*, 24 **(1981)** 10-16.

Yeow P.H.P.; Sen R.N.: "Ergonomic improvements of workstations for visual inspection and electrical test in a multimedia product factory", *Proceedings of the Human Factors and Ergonomics Society 44th Annual Meeting,* San Diego, California, USA, July 30-August 4, **(2000)** 107 - 110.

Yeow P.H.P.; Sen R.N.; "Quality, productivity, occupational health and safety and cost effectiveness of ergonomic improvements in the test workstations of an electronic factory", *International Journal of Industrial Ergonomics,*32 **(2003)** 147 - 163.

APPENDICES

APPENDIX - A

QUICK EXPOSURE CHECK (QEC) QUESTION FORM AND SCORING TABLE

Worker's name ______________________________ Date ______________

Observer's Assessment

Back

A **When performing the task, is the back**
(select worse case situation)

A1 Almost neutral?
A2 Moderately flexed or twisted or side bent?
A3 Excessively flexed or twisted or side bent?

B **Select ONLY ONE of the two following task options:**

EITHER

For seated or standing stationary tasks. **Does the back remain in a static position most of the time?**

B1 No
B2 Yes

OR

For lifting, pushing/pulling and carrying tasks (i.e. moving a load). **Is the movement of the back**

B3 Infrequent (around 3 times per minute or less)?
B4 Frequent (around 8 times per minute)?
B5 Very frequent (around 12 times per minute or more)?

Shoulder/Arm

C **When the task is performed, are the hands**
(select worse case situation)

C1 At or below waist height?
C2 At about chest height?
C3 At or above shoulder height?

D **Is the shoulder/arm movement**

D1 Infrequent (some intermittent movement)?
D2 Frequent (regular movement with some pauses)?
D3 Very frequent (almost continuous movement)?

Wrist/Hand

E **Is the task performed with**
(select worse case situation)

E1 An almost straight wrist?
E2 A deviated or bent wrist?

F **Are similar motion patterns repeated**

F1 10 times per minute or less?
F2 11 to 20 times per minute?
F3 More than 20 times per minute?

Neck

G **When performing the task, is the head/neck bent or twisted?**

G1 No
G2 Yes, occasionally
G3 Yes, continuously

Worker's Assessment

Workers

H **Is the maximum weight handled MANUALLY BY YOU in this task?**

H1 Light (5 kg or less)
H2 Moderate (6 to 10 kg)
H3 Heavy (11 to 20kg)
H4 Very heavy (more than 20 kg)

J **On average, how much time do you spend per day on this task?**

J1 Less than 2 hours
J2 2 to 4 hours
J3 More than 4 hours

K **When performing this task, is the maximum force level exerted by one hand?**

K1 Low (e.g. less than 1 kg)
K2 Medium (e.g. 1 to 4 kg)
K3 High (e.g. more than 4 kg)

L **Is the visual demand of this task**

L1 Low (almost no need to view fine details)?
*L2 High (need to view some fine details)?
* *If High, please give details in the box below*

M **At work do you drive a vehicle for**

M1 Less than one hour per day or Never?
M2 Between 1 and 4 hours per day?
M3 More than 4 hours per day?

N **At work do you use vibrating tools for**

N1 Less than one hour per day or Never?
N2 Between 1 and 4 hours per day?
N3 More than 4 hours per day?

P **Do you have difficulty keeping up with this work?**

P1 Never
P2 Sometimes
*P3 Often
* *If Often, please give details in the box below*

Q **In general, how do you find this job**

Q1 Not at all stressful?
Q2 Mildly stressful?
*Q3 Moderately stressful?
*Q4 Very stressful?
* *If Moderately or Very, please give details in the box below*

* *Additional details for L, P and Q if appropriate*

* L

* P

* Q

Back

Back Posture (A) **& Weight** (H)

	A1	A2	A3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 1

Back Posture (A) **& Duration** (J)

	A1	A2	A3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 2

Duration (J) **& Weight** (H)

	J1	J2	J3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 3

Now do ONLY 4 if static
OR 5 and 6 if manual handling

Static Posture (B) **& Duration** (J)

	B1	B2
J1	2	4
J2	4	6
J3	6	8

Score 4

Frequency (B) **& Weight** (H)

	B3	B4	B5
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 5

Frequency (B) **& Duration** (J)

	B3	B4	B5
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 6

Total score for Back
Sum of scores 1 to 4 OR
Scores 1 to 3 plus 5 and 6 ______

Shoulder/Arm

Height (C) **& Weight** (H)

	C1	C2	C3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 1

Height (C) **& Duration** (J)

	C1	C2	C3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 2

Duration (J) **& Weight** (H)

	J1	J2	J3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 3

Frequency (D) **& Weight** (H)

	D1	D2	D3
H1	2	4	6
H2	4	6	8
H3	6	8	10
H4	8	10	12

Score 4

Frequency (D) **& Duration** (J)

	D1	D2	D3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 5

Total score for Shoulder/Arm
Sum of Scores 1 to 5 ______

Wrist/Hand

Repeated Motion (F) **& Force** (K)

	F1	F2	F3
K1	2	4	6
K2	4	6	8
K3	6	8	10

Score 1

Repeated Motion (F) **& Duration** (J)

	F1	F2	F3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 2

Duration (J) **& Force** (K)

	J1	J2	J3
K1	2	4	6
K2	4	6	8
K3	6	8	10

Score 3

Wrist Posture (E) **& Force** (K)

	E1	E2
K1	2	4
K2	4	6
K3	6	8

Score 4

Wrist Posture (E) **& Duration** (J)

	E1	E2
J1	2	4
J2	4	6
J3	6	8

Score 5

Total score for Wrist/Hand
Sum of Scores 1 to 5 ______

Neck

Neck Posture (G) **& Duration** (J)

	G1	G2	G3
J1	2	4	6
J2	4	6	8
J3	6	8	10

Score 1

Visual Demand (L) **& Duration** (J)

	L1	L2
J1	2	4
J2	4	6
J3	6	8

Score 2

Total score for Neck
Sum of Scores 1 to 2 ______

Driving

M1	M2	M3
1	4	9

Total for Driving ______

Vibration

N1	N2	N3
1	4	9

Total for Vibration ______

Work pace

P1	P2	P3
1	4	9

Total for Work pace ______

Stress

Q1	Q2	Q3	Q4
1	4	9	16

Total for Stress ______

APPENDIX - B

FURTHER ANALYSES ON MS DISCOMFORT SEVERITY AND EXPOSURE TO ERGONOMICS RISK FACTORS

*** Results of Analysis of Variance (ANOVA) on MS discomfort severity ratings after ergonomics interventions with independent factor: Using tilted or flat (non-tilted) sewing machines**

E. Do you feel discomfort (pain, numbness, tingling etc.) in ...

Anchors: No(1) Slightly(2) Moderately(3) Severely (4)

	Tilted machine (n=15)		Flat machine (n=15)		ANOVA	
	Mean	Std.d	Mean	Std.d	F	P
Neck	1,800	,774	1,866	,990	,042	,839
Right shoulder	1,466	,743	1,800	,941	1,159	,291
Left shoulder	1,533	,9904	1,800	1,146	,465	,501
Upper back	1,866	,9904	2,333	1,234	1,304	,263
Low back	2,133	1,060	2,733	1,162	2,181	,151
Right arm	1,600	,9103	1,666	,975	,037	,848
Left arm	1,466	,7432	1,333	,6172	,286	,597
Right wrist	1,333	,8997	1,600	1,121	,516	,478
Left wrist	1,466	,9904	1,266	,7988	,371	,548
Right hand	1,333	,8997	1,466	,9904	,149	,702
Left hand	1,200	,7746	1,266	,7988	,054	,818
Right leg	1,800	1,014	2,066	1,162	,448	,509
Left leg	1,866	1,245	1,866	,9155	,000	1,000
Right foot	1,266	,5936	1,800	1,146	2,560	,121
Left foot	1,600	1,121	1,800	,9411	,280	,601

*** Results of Analysis of Variance (ANOVA) on mean frequency of exposure to ergonomics risk factors after ergonomics interventions with independent factor: Using tilted or flat (non-tilted) sewing machines**

C.During work, do you… Anchors: No(1) Sometimes(2) Frequently(3) Always(4)

	Tilted machine (n=15)		Flat machine (n=15)		ANOVA	
	Mean	Std.d	Mean	Std.d	F	P
C1.Bend your upper body?	1,933	,798	2,200	1,014	,640	,430
C2.Bend your neck?	2,200	,676	2,466	,915	,824	,372
C3.Feel visual discomfort?	1,400	,507	1,400	,828	,000	1,00
C4.Feel obstructed by engine etc. underneath the table?	1,266	,457	1,200	,560	,127	,724
C5.Have to reach extensively?	1,533	,516	1,533	,915	,000	1,000
C6. Bend your wrists?	1,733	,798	2,200	1,014	1,960	,172
C7. Lean your arms on sharp edges?	1,333	,617	1,200	,560	,384	,541
C8.Find your rest breaks insufficient?	1,266	,798	1,133	,516	,295	,591

*** Results of Wilcoxon Sign Rank (WSR) test on before/after MS discomfort severity ratings of operators who reported reduction in MS discomfort after ergonomics interventions**

E. Do you feel discomfort (pain, numbness, tingling etc.) in ... Anchors: No(1) Slightly(2) Moderately(3) Severely (4)	BEFORE(n=13)		AFTER(n=13)		Wilcoxon Sign Rank Test	
	Mean	Std.d	Mean	Std.d	F	P
Neck	2,076	1,037	1,692	,854	-1,406	,080
Right shoulder	1,923	1,187	1,692	,854	-,551	,291
Left shoulder	1,692	1,031	1,461	,776	-,707	,240
Upper back	2,384	1,192	2,000	1,080	-1,155	,124
Low back	2,307	,854	1,846	,898	-1,613	,054
Right arm	1,615	1,043	1,615	,960	-,138	,445
Left arm	1,153	,554	1,230	,599	,272	,606
Right wrist	1,076	,277	1,384	,960	1,069	,857
Left wrist	1,307	,751	1,384	,960	,378	,646
Right hand	1,461	,967	1,384	,960	-,136	,445
Left hand	1,000	,000	1,230	,832	1,00	,841
Right leg	1,384	,650	1,230	,438	-,707	,240
Left leg	1,846	,800	1,615	,960	-1,342	,090
Right foot	1,230	,599	1,230	,438	,000	,500
Left foot	1,615	1,043	1,692	,947	,108	,571

BIOGRAPHY

Oğuzhan Erdinç was born in Ankara, 1973. After graduation from Maltepe Military College, İzmir, he attended to Air Force Academy, Industrial Engineering Department, İstanbul. He was graduated from Academy in 1995 as a lieutenant and Industrial Engineer. He was assigned to 2nd Air Base as Flight Trainee Officer. After quitting flight training, he was assigned to 5th Air Base as a logistics officer. He was invited to Air Force Academy to be an instructor in 1999.

He attended to graduate program in Marmara University, Industrial Engineering Programme the same year. Following the completion of graduate programme, he continued wtih Ph.D. programme in the same department. His research interest was focused on ergonomics. He has taught ergonomics in Air Force Academy IE department for five years. He also taught ergonomics in Marmara University Engineering Faculty, undergraduate programme for two years. He has participated in several national/international academic events on ergonomics as presenter and speaker. He continues his academic career in Air Force Academy.

He is married and living in İstanbul.