Ergonomic design interventions for improvement of shop-floor working conditions in the Indian small and medium scale injection-molded plastic furniture manufacturing industries

A thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Submitted by

Sanjog J.

(Roll No: 11610501)

Under the supervision of

Dr. Sougata Karmakar

Department of Design

Indian Institute of Technology Guwahati

Guwahati - 781039, Assam, India.

Dedicated to my parents

Declaration Certificate

February 2016

I hereby declare that the thesis entitled 'Ergonomic design interventions for improvement of shop-floor working conditions in the Indian small and medium scale injection-molded plastic furniture manufacturing industries' being submitted in the partial fulfillment for the award of PhD degree, is an authentic work of my research work carried out during the period from July 2011 to June 2015 in the Department of Design, Indian Institute of Technology Guwahati under the supervision of Dr. Sougata Karmakar. The thesis has not been submitted by me earlier for any other degree or diploma.

Sanjog. J.
Roll No. 11610501,
Department of Design,
Indian Institute of Technology Guwahati,
Guwahati - 781039, Assam, India.

Certificate

February 2016

The thesis entitled 'Ergonomic design interventions for improvement of shop-floor working conditions in the Indian small and medium scale injection-molded plastic furniture manufacturing industries' presented herein by Mr. Sanjog J. (Roll No. 11610501) was undertaken under my supervision. The volume of work submitted for the degree of Doctor of Philosophy of the Indian Institute of Technology Guwahati has not been submitted by him earlier for any other diploma or degree.

He has undergone four specified courses and fulfilled all the requirements as mentioned in the rules and regulations for submitting the thesis for the PhD degree of the Indian Institute of Technology Guwahati.

Dr. Sougata Karmakar,
Department of Design,
Indian Institute of Technology Guwahati,
Guwahati - 781039, Assam, India.

Preface

Micro Small and Medium Enterprises (MSMEs) are intended to be labor intensive for providing large employment opportunities at lower capital cost. MSMEs offer significant employment opportunities next only to agriculture sector in the Indian scenario. MSMEs are the main contributors towards the growth of the Indian economy and provide large employment opportunities. Work comprising of manual labor is a distinctive shop-floor feature of Indian MSMEs in the manufacturing sector. Ergonomics forms a critical issue as MSMEs in the manufacturing sector is highly labor intensive. In Indian scenario, ignorance towards ergonomics, the science of human–machine compatibility is prominent across all industries. The prevalence of occupational health issues (awkward working postures, repetitive activities, heavy manual load handling etc.) have been reported by ergonomists and occupational health researchers in Indian MSMEs. Ergonomic aspects are not given much thought while commissioning and installing majority of the production units in India. As a result, durable goods manufacturing industries in India are far from being human centric affecting the workers' well-being. Very limited efforts have been taken to investigate the ergonomic aspects in the durable goods manufacturing shop-floor.

Indian plastic processing industries have promising growth potential, capabilities for a huge employment generation, and are highly fragmented consisting of MSMEs. The establishment of petrochemical industries is fuelling the growth of plastic processing industries in India. Completion of Assam gas cracker project is expected to tremendously increase plastic processing activities in the state of Assam and the entire North Eastern region of India involving huge human resources.

Investigations from an ergonomics perspective for identifying the need for ergonomic design interventions have not been performed in Indian plastic processing industry till date. Foreseeing the tremendous growth potential of plastic processing activities in India and particularly in North East India, it is the right time to conduct investigations from an ergonomics perspective in the existing plastic processing industries. Seven injection-molded plastic furniture manufacturing factories (under the small and medium sector) in the state of Assam were identified. Authors were permitted by four company managements for conducting investigations. The non-disclosure agreement regarding identification of those factories compelled to keep them anonymous. Production processes in the shop-floor were centered on blending (mixing), granulator (grinding/scrap grinder) and injection-molding workstations. The present research work aims to investigate the shop-floor working conditions in workstations of small and medium scale injection-molded plastic furniture manufacturing industries and propose design interventions for improving the shop-floor working conditions from an ergonomics perspective.

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Sanjog J.

Abstract

Manual labour and locally designed workplace fixtures are prevalent in Indian plastic processing industry which is highly fragmented, comprising of Micro Small and Medium Enterprises (MSMEs). In Indian scenario, investigations pertaining to workstation design and layout from a broad perspective of ergonomics, occupational health and indoor work environment have not been performed till date in the shop-floor of small and medium scale injection-molded plastic furniture manufacturing industries.

The present research aimed to investigate and propose design interventions for improving shop-floor working conditions from an applied ergonomics view point. To accomplish the stated aim, combination of research methods featuring literature survey, questionnaire study, postural assessment tools, direct observation, statistical analysis, work study technique, virtual human modeling and simulation has been used.

Existing shop-floor workstations and work accessories were designed without considering ergonomics principles and thus led to the occurrence of risky work postures. Moreover, indoor work environmental conditions were not in accordance with recommendations. Ergonomics and indoor environmental factors were not considered while designing shop-floor layouts. Statistical model derived from present research established that occurrence of symptoms of musculoskeletal ailments due to awkward working postures and bad workstation design; is exacerbated if work shift duration is longer. Significant ($p < 0.05$) reduction in hand grip strength before and after work indicated the likelihood of shop-floor workers developing upper limb musculoskeletal disorders in due course of time.

Virtual evaluations, work study techniques, psychosocial and subjective work load assessments deployed in the present research were helpful for designing concept workstations and work-accessories. Redesign of workstation and work methods in accordance with recommended guidelines enabled downgrading the risk perception of work postures. Context specific suggestions were also proposed for improving indoor work environment. A conceptual shop-floor layout was developed incorporating guidelines proposed in published literatures.

Business houses interested in expanding or establishing new injection-molded plastic furniture manufacturing factories in the small and medium sector will find the results of the current research endeavor highly beneficial. Research methodology and design interventions as demonstrated in current study may be easily adopted by engineers / managers / supervisors in MSMEs of industrially developing countries towards implementing validated context specific human centric production systems.

Summary of the research

Introduction

Ignorance towards ergonomics, the science of human machine compatibility is prominent across the manufacturing sectors in India. Ergonomic aspects of factory layouts, workstations, work methods and work environments were not given much thought while commissioning and installing the majority of Indian manufacturing industries. Very limited efforts have been taken to investigate the ergonomics aspects of the manufacturing shop-floor. However the current focus is on increasing labor intensive employment opportunities for the people of India. Hence, the discipline of ergonomics should be applied for optimizing the human machine interaction for enhanced safety, comfort and wellbeing of the workers involved in the manufacturing sector.

Background, Research Gap and Problem statement

India is taking aspiring growth oriented steps in the manufacturing sector through its 'Make in India' campaign. One of the aims of 'Make in India' promotion is to create employment opportunities for the people. Various sectors have been identified for attracting investments. The 'chemicals' sector is one of them. It is reported that India is the third largest consumer of plastics in the whole world and offers tremendous growth potential. The plastic industry is one of the fastest growing industries in India. Clothing, construction, furniture, automobiles, agriculture, irrigation, packaging, medical appliances, electronics and electrical products are some of the sectors which are filled with petrochemical products. The plastics processing industries convert bulk polymeric material into finished articles. Types of conversion process include compression-molding, transfer-molding, injection-molding, extrusion-molding, blow-molding, rotational-molding, thermoforming, film casting calendaring and laminating.

Petrochemical projects across the country and the emphasis on making India a global manufacturing hub is expected to tremendously increase plastic processing activities in the country. Subsequently a huge labor force is also expected to be employed in the plastic processing sector. The Indian plastic processing industries are highly fragmented consisting of Micro Small and Medium Enterprises (MSMEs).

MSMEs offer huge employment opportunities and significantly contribute to the manufacturing output. The Government of India is promoting greater manufacturing activities in the North Eastern regions through various policies like Micro Small and Medium Enterprise (MSME) Act 2006 and the North-East Industrial and Investment Promotion Policy. The Government of Assam is also trying to attract investments for the establishment of industries through its Industrial and Investment Policy of 2014. The completion of Assam gas cracker project named Brahamaputra Cracker and Polymer Limited (BCPL) is being eagerly looked forward by the plastic processing industry. The Government of Assam is planning to build a 'Plastic Park' (about 50 km from the project site) which is estimated to give rise to numerous plastic processing units and subsequently expected to increase the plastic processing activities with the generation of huge employment opportunities throughout the State of Assam and the entire North East region. Therefore, in this context, investigations into the existing manufacturing workstations and associated work activities / methods resulting in guidelines for design interventions and work methods from an ergonomics perspective is sure to benefit the existing small and medium scale plastic processing industry and the labor force employed in this sector. Additionally such an effort will definitely help enterprises desiring to set up new manufacturing units to proactively implement ergonomics in the workstations designs, thus deriving its associated benefits for all stake holders. Foreseeing increased plastic processing activities in India and particularly in North East India, it is the appropriate time to conduct investigations from an ergonomics perspective in the existing plastic processing industries. Injection-molded plastic furniture manufacturing industries are an integral part of the plastic processing sector. Various types of consumer durables are manufactured by injection-molded plastic furniture manufacturers in India. Some of them include chairs, dining tables, sitting stools and baby chairs. Following literature review, it is observed that there is no reported study on investigations concerning the workstation design and layout design of shop-floor with respect to small and medium scale injection-molded plastic furniture manufacturing industries in India. Seven injection-molded plastic furniture manufacturing factories (under the small and medium scale sector) in the state of Assam, India were identified for the present study. Permission was granted by four company managements for conducting investigations in their factories. The non-disclosure agreement regarding identification of those factories compelled to keep them anonymous. The production processes in shop-floor was centered on blending (mixing), granulator (grinding / scrap grinder) and injection-molding workstations.

Aim and Objectives

The research work aims to investigate the shop-floor working conditions in workstations of the Indian small and medium scale injection-molded plastic furniture manufacturing industries in Assam (a north-eastern state of India) and propose design interventions towards improving shop-floor working conditions from an ergonomics perspective.

The following objectives were framed in order to achieve the stated aim.

1. Investigate the occurrence of awkward working postures and prevalence of symptoms of musculoskeletal ailments among shop-floor workers.
2. Assess the contributing role of workstation design (WD), working postures (WP) and work shift duration (WSD) towards symptoms of musculoskeletal ailments (SMA) and to find out the inter-relationships among all these factors.
3. Assess the hand grip strength before and after work for identifying the susceptibility of shop-floor workers for developing upper limb body part musculoskeletal disorder in due course of time.
4. Ergonomic assessment shop-floor workstations for identifying and estimating the extent of various risk factors (physical, psychosocial and subjective work load) and proposing design interventions, if required.
5. Investigate important indoor environmental parameters from a physical ergonomics perspective for proposing context specific recommendations, if required.
6. Investigate shop-floor layout design practices from physical and environmental ergonomics aspects for proposing context specific recommendations, if required.

Hypotheses

Factory visits were made initially to observe and understand the prevailing working conditions. After review of literature and discussions with supervisors / managers the following three hypotheses were formulated for ensuring a proper direction to the research work.

1. **H_1** - Awkward postures, improper workstation design and prolonged work shift duration in the shop-floor of the Indian small and medium scale injection-molded plastic furniture manufacturing industries are significantly contributing (stand-alone / cumulative) to the incidence of the symptoms of musculoskeletal ailments among workers.
2. **H_2** - Ergonomic design intervention in terms of modifications of workstation accessories might be a definite solution for avoiding awkward posture in the shop-floor of the Indian small and medium scale injection-molded plastic furniture manufacturing industries.
3. **H_3** - Redesign of shop-floor layout and improvement in the physical work environment (air movement, temperature, relative humidity, illumination and noise level) is crucial for humanizing working conditions in the shop-floor of the Indian small and medium scale injection-molded plastic furniture manufacturing industries.

Methodology

The demographic details of the workers were collected using a personal information questionnaire. Standing height and weight of the workers / employees were measured at the factory. The shop-floor workers constituted the experimental group. A control group consisting of administrative and supervisory employees was constituted to compare the incidence of symptoms of musculoskeletal ailments with the experimental group. Information pertaining to the prevalence of the symptoms of musculoskeletal ailments was collected using the Standardized Nordic Questionnaire (SNQ). Continuous videography was not permitted by factory managements. Hence, direct observations and photography was used to observe and record the work activities in the shop-floor. The work elements (in a work cycle) in the shop floor workstations involved the use of the entire body. Therefore Ovako Working Posture Analysis System (OWAS) and Rapid Entire Body Assessment (REBA) techniques were used for postural assessment. The psychosocial work environment was assessed using the Copenhagen Psychosocial Questionnaire (COPSOQ) II - medium version. The Subjective work load assessment was performed using the National Aeronautics and Space Administration - Task Load Index (NASA – TLX) technique. Statistical analysis of collected data sets was performed using SPSS v.20 (IBM, USA) software. Delmia (V5R19) digital human modeling and simulation software was used to construct Digital Human Models (DHM) representing the adult Indian male population. Comfort angles for different body segments were rendered over the digital human models. The dimensions of the shop-floor workstations were measured at the factory site and CAD (Computer Aided Design) models of the existing shop-floor workstations were constructed. Shop-floor workstation and digital human models were interfaced for postural comfort assessments. Following identification of postural and comfort risks, suitable modifications were made in the workstation designs (in CAD models) and further evaluated in virtual environment using digital human modeling software for designing human centric manufacturing activities in the shop-floor. Method study with the help of operation chart (left and the right hand) and work measurement using time study were the work study techniques used for studying, investigating and recording work elements and also for evaluating the effectiveness of design interventions proposed. Indoor work environment (air movement, temperature, relative humidity, illumination and noise level, etc.) was measured for one complete year with the aim of identifying location specific and season specific risks. Hand held pocket weather meter, globe thermometer, sling psychrometer and light meter was used for measuring various indoor environmental parameters. Direct observation, photography and flow diagram using process chart symbols was used to investigate the shop-floor material movements in order to propose modifications for the shop-floor layout incorporating ergonomics and indoor work environment parameters.

Results and Discussion

Symptoms of musculoskeletal ailments were observed among workers in the shop-floor workstations. **Thus the objective - 1 of the research work is accomplished.** The occurrence of the symptoms of musculoskeletal ailments (discomfort, pain and ache) during the work was significantly higher for the experimental group (blending, granulator, injection-molding workers) when compared with the control group. Awkward working postures, prolonged work shift duration and bad workstation design were established as risk factors for the high prevalence of symptoms of musculoskeletal ailments among workers in shop-floor workstations. The influence of working postures and workstation design on symptoms of musculoskeletal ailments was found to be significantly ($p < 0.05$) mediated through work shift duration. **Thus the objective - 2 of the research work is accomplished.** Symptoms of musculoskeletal ailments due to awkward working posture and bad workstation design were exacerbated in prolonged work shift duration. **Thus the hypothesis - H_1 of the research work is established**. Regulating work shift duration could be the solution for reducing the occurrence of the symptoms of musculoskeletal ailments in small and medium scale injection-molded plastic furniture manufacturing industries; if the scope for correcting poor work station design, changing working postures and subsequent modification of work methods are limited / constrained by other factors.

Significant reduction in hand grip strength before and after work in both the hands was observed among shop-floor workers. **Thus the objective - 3 of the research work is accomplished.** Reduction in hand grip strength may indicate the likelihood of shop-floor workers developing upper limb musculoskeletal disorders in due course of time. Hence, it is necessary that design interventions towards realizing human centric production systems should be implemented in the shop-floor workstations of small and medium scale injection-molded plastic furniture manufacturing industries.

Machine shop workstations in injection-molded plastic furniture manufacturing industries comprise of workstation fixtures / accessories designed by native people lacking basic ergonomics knowledge. This scenario has led to the prevalence of physical mismatch between the worker's anthropometry and overall workstation design resulting in awkward working postures. Evaluations were performed virtually using digital human modeling software for aiding workstation design interventions for reducing the incidence of awkward working postures. Digital human modeling software was helpful in aiding examinations of existing shop-floor workstations in a realistic manner without the necessity of building costly real physical mockups and trials involving real humans. Psychosocial and subjective work load assessments were helpful for formulating workstation design intervention strategies. Work study techniques were helpful in visualizing the impact of workstation design interventions on work activities. Research outcome (**fulfilling objective - 4 of the research work**) towards the modification of work method and redesigning of workstations considering demographic constraints enabled to significantly downgrade the risk perception of the working postures. **Thus the hypothesis - H_2 of the research work is established**.

The prevailing indoor work environment (air movement, temperature, relative humidity, illumination and noise level) in the shop-floor was observed and recorded. Comparisons of prevailing indoor environmental conditions with guidelines specified by scientific organizations and researchers indicated the need for context specific corrective actions. Observations were segregated based on climatic seasons and locations. Seasonal (climatic) and location specific risks were identified and guidelines have been proposed. **Thus the objective - 5 of the research work is accomplished.** Micro small and medium enterprises in industrially developing countries like India are intended to be labor intensive for the generation of large employment opportunities and therefore complete automation of the production processes is not feasible. Hence, suitable modifications in the immediate working environment and guarding humans may be adopted by the existing plastic processing industries for humanizing work environment. Physical and environmental ergonomic aspects were not considered while designing shop-floor layouts in small and medium scale injection-molded plastic furniture manufacturing industries. Problems in prevailing layouts and context specific guidelines from published literature have been highlighted. **Thus the objective - 6 of the research work is accomplished.** A conceptual shop-floor layout was developed incorporating guidelines based on physical and environmental ergonomic perspective. Redesign of shop-floor layout and improvement in the physical work environment (temperature, illumination and noise level) is crucial for humanizing working conditions in the shop-floor. **Thus the hypothesis - H_3 of the research work is established**.

Conclusion

Present research work has established that ergonomics risk factors are prevalent in shop-floors of small and medium scale injection-molded plastic furniture manufacturing industries and such risk factors may be mitigated successfully with the help of suitable low cost design interventions. Low cost design interventions / strategies are practically feasible solutions for mitigating risk factors, as micro small and medium enterprises are intended to be labor intensive and have governmental restrictions on capital investment. The combination of research methods featuring questionnaire study, postural assessment tools, statistical analysis, direct observation, digital human modeling and work study technique was successful in identifying risk factors and in designing context specific validated design interventions.

The research methodology followed in present research work is perhaps first of its kind towards investigations from an ergonomics perspective in micro small and medium enterprises in India. Digital human modeling and simulation helped in evaluating, existing and proposed workstation designs and work methods without the construction of real physical prototypes and trials involving real human beings. Research methodology utilized in present research work may be easily adopted by researchers, production supervisors / managers / engineers towards implementing context specific ergonomic design solutions in the manufacturing sector shop-floor of industrially developing countries.

Business houses interested in expanding or establishing new injection-molded plastic furniture manufacturing factories in the small and medium sector will find the results of the current research endeavor highly beneficial. The innovative combination of research methodologies used in the present research endeavor may be replicated by initiating similar investigations in other sectors in order to identify industry specific problems and propose contextual solutions.

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List of abbreviations

ASEAN	-	Association of Southeast Asian Nations
ASHRAE	-	American Society of Heating, Refrigerating and Air Conditioning Engineers)
BIS	-	Bureau of Indian Standards
BCPL	-	Brahmaputra Cracker and Polymer Limited
CAGR	-	Compound Annual Growth Rate
Cr	-	Crore
DBT	-	Dry Bulb Temperature
DHM	-	Digital Human Modeling
DHMS	-	Digital Human Modeling and Simulation
GT	-	Globe Temperature
FY	-	Financial Year
HDPE	-	High Density Polyethylene
HPL	-	Haldia Petro chemicals Limited
IDC	-	Industrially Developing Countries
INR	-	Indian National Rupees
KTA	-	Kilo Tons per Annum
LLDPE	-	Linear Low Density Polyethylene
MMT	-	Million Metric Tons
MnMT	-	Million Metric Tons
MRT	-	Mean Radiant Temperature
MSMEs	-	Micro Small and Medium Enterprises
NEIIPP	-	North-East Industrial and Investment Promotion Policy
NRL	-	Numaligarh Refinery Limited
PMV	-	Predicted Mean Vote
PPD	-	Predicted Percentage of Dissatisfied

RH	-	Relative Humidity
Rs	-	Rupees
SMA	-	Symptoms of Musculoskeletal Ailments
TPA	-	Tonnes per Annum
WBT	-	Wet Bulb Temperature
WBGT	-	Wet Bulb Globe Temperature
WD	-	Workstation design
WMSDs	-	Work-related Musculoskeletal Disorders
WP	-	Working Postures
WSD	-	Work Shift Duration

Chapter - I

Introduction

Abstract

The Indian manufacturing scenario in the small and medium sector is expected to make rapid growth offering large labor intensive employment opportunities due to the ambitious 'Make in India' programme. However, occupational health related issues are prevalent in the existing small and medium scale industries in the Indian manufacturing sector. Plastic processing industries in India consists of small and medium scale industries. Investigations focused on the identification of the occupational health risks from an ergonomics perspective and proposals to mitigate risks if any, have not been attempted in the Indian plastic processing industries. The injection-molded plastic furniture manufacturing industries form an important constituent in the plastic processing sector. Foreseeing tremendous growth potential of plastic processing industries in India, investigations from an ergonomics perspective in the existing industries are very much needed for humanizing work and work environment.

1.1 Global petrochemical industry

Petrochemicals are important for economic development and the global petrochemical industry is growing at 1.2 - 1.3 times the global Gross Domestic Product (GDP) growth (Government of India, 2012). The global chemical market is estimated to be US$ 3.3 trillion with petrochemicals constituting the single biggest segment (Government of India, 2012). Polymeric materials categorized as commodity, engineering and specialty plastics are produced from petrochemicals for meeting the needs of different sectors of the economy (Government of India, 2012). Plastic is one of the fastest growing industries and will definitely shape the world's future with respect to material usage. Plastics help to significantly reduce the burden on natural resources by gradually replacing materials like wood, metals, etc. The global demand for commodity plastics increased from 123 Million Metric Tons (MMT) in 2000 to 169 MMT in 2010, while the global polymer capacity went up from 142 MMT to 213 MMT in the same period (Government of India, 2012). After the year 2000, Asia and Middle East regions are the biggest contributors for the growth of petrochemical industries (Government of India, 2012). The huge amount of petrochemicals activities are shifting to countries like China and India due to the massive consumption potential and feedstock advantage (Government of India, 2012).

1.2 Indian plastic industry

The plastics industry is one among the fastest growing industries in India (Federation of Indian Chambers of Commerce and Industry, 2014 a). India is being viewed as a country, offering an enormous opportunity for increased plastics consumption as the per capita plastics consumption very low in India when compared with many developed nations (Federation of Indian Chambers of Commerce and Industry, 2014 a). When compared to per capita consumption of plastics in USA at 109 kg, China at 29 kg and Brazil at 32 kg, India at 5kg (if recycled material is included) is still in nascent stage, while the world average per capita consumption is 18 kg thus reflecting on the Indian plastic consumption growth rate (16%) which is higher than China (10%) and other key Asian countries (Mutha et al. 2006).

1.3 Indian plastic processing industries

Industries dedicated to manufacturing of polymers are termed as the ‘upstream petrochemical industries’ and those involved in conversion of polymers into plastic articles are known as ‘downstream plastic processing industries’ (Central Institute of Plastics Engineering and Technology, 2010). The Indian plastic processing industry has grown at a Compound Annual Growth Rate (CAGR) of 10% from Rs. 35,000 Cr. in Financial Year (FY) '05 to Rs. 90,000 Cr. in FY '14 in terms of value (Federation of Indian Chambers of Commerce and Industry, 2014 b). The Indian plastic processing industry is expected to grow at a CAGR of 10% between FY '13 to FY '18 to reach 18 MnMT and the turnover is expected to reach Rs. 1, 37, 000 Cr. by FY '18 (Federation of Indian Chambers of Commerce and Industry, 2014 b). Considering both direct and indirect employment, the plastic processing industry presently provides employment to 3.3 million people and depending upon consumption growth within the country, the sector has the potential of generating 3 million additional employment opportunities (Central Institute of Plastics Engineering and Technology, 2010). Emergence of India as a key exporter of value added plastic products like China, can hasten the growth of plastic processing industries (Central Institute of Plastics Engineering and Technology, 2010). India is emerging as one among the important destination for downstream plastic processing activities worldwide due to increase in domestic consumption (Federation of Indian Chambers of Commerce and Industry, 2014 b).

The Indian plastic processing industries offer tremendous potential for growth in the coming years aided by the present government's 'Make in India' campaign (Federation of Indian Chambers of Commerce and Industry, 2014 b). The Indian Plastic processing industries can contribute to the country's dream of becoming a manufacturing hub by attracting foreign investments (Federation of Indian Chambers of Commerce and Industry, 2014 b). Attention should be paid to the growth of downstream plastic processing industries as the supply of plastics has increased tremendously (Federation of Indian Chambers of Commerce and Industry, 2014 a).

It was reported in the year 2010 that there were about 26,000 registered plastic processing units in India of which about 75% are in small-scale sector accounting for about 25% of polymer consumption and the industry also consumes recycled plastic, which constitutes about 30% of total consumption in India (Central Institute of Plastics Engineering and Technology, 2010). Based on a survey of 60 Indian cities it was found that there are 3500 organized and 4000 un-organized recycling units (Central Institute of Plastics Engineering and Technology, 2010) and it is reported that 60 % of plastics in India is recycled wherein recycling capacity of India is much more than the scrap available to run it (Business Standard, 2012). The total number of plastic processing units is approximately 30,000 (mostly in the small scale sector) generating revenues of approximately INR 900 Bn in FY '14 (Federation of Indian Chambers of Commerce and Industry, 2014 b). In India, the upstream polymer manufacturers have commissioned globally competitive plants with imported state-of-art technology from world leaders, whereas, the downstream plastic processing industry is highly fragmented and consists of micro, small and medium units (Central Institute of Plastics Engineering and Technology, 2010). The downstream industry is further classified based on the process, namely, injection-molding, blow-molding and extrusion-molding; meeting the requirements of a wide range of applications like packaging, automobile, consumer durables, healthcare, etc. (Central Institute of Plastics Engineering and Technology, 2010). The plastics processing industry converts bulk polymeric material into finished articles. Types of conversion process include compression molding, transfer molding, injection-molding, extrusion-molding, blow-molding, rotational-molding, thermoforming, film casting calendaring, laminating, etc. The Extrusion process is the most commonly used process in Indian downstream plastic processing industries accounting for 60% of total consumption of polymers (Federation of Indian Chambers of Commerce and Industry, 2014 b). Injection-molding is the second highest process accounting for 25% of consumption followed by blow-molding (5%) and roto-molding (1%) while the remaining is processed through specialized processes (Federation of Indian Chambers of Commerce and Industry, 2014 b). It was projected in the year 2010 that, an additional 40,800 plastic processing machines are expected to be installed by 2014-15 in the Indian plastic processing Industry (Central Institute of Plastics Engineering and Technology, 2010). Segment wise break-up is injection-molding 26,700 Nos., blow-molding 3,900 Nos., and extrusion 10,200 Nos., (Central Institute of Plastics Engineering and Technology, 2010). Machine additions and investments in the Indian plastic processing sector are shown in table 1.1.

Table No. 1.1

Machine addition and investments in the Indian plastic processing industries

Year	Up to 2001-2002	Total (as of 31.3.2010)	Increase over 2001-2002	Share in total	Additional machines expected to be installed by 2014-2015
No. of Machines (No.)					
Injection-molding	31020	51598	20578	**60.8 %**	**26,700**
Blow-molding	4843	7300	2457	8.6 %	3900
Extrusion-molding	15905	25938	10033	30.6 %	10,200
Total	51768	84836	33068		40,800
Capacity (kTA)					
Injection-molding	1984	5198	3214	**27.1 %**	NA
Blow-molding	511	900	389	4.7 %	NA
Extrusion-molding	5744	13080	7336	68.2 %	NA
Total	8239	19178	10939		
Investments (Rs crores)					
Injection-molding	5420	10570	5150	**52.8%**	NA
Blow-molding	386	660	274	3.3%	NA
Extrusion-molding	4057	8787	4731	43.9%	NA
Total	9863	20017	10155		

Legends: KTA - Kilo Tons per Annum

(adopted from Central Institute of Plastics Engineering and Technology, 2010)

1.4 Plastic processing: injection-molded plastic furniture manufacturing

The plastics-processing industry converts bulk polymeric material into finished articles. Injection-molded plastic furniture manufacturing industries are an integral part of the plastic processing industry. Various types of consumer durables are manufactured by molded plastic furniture manufacturers in India. Some of them include chairs (high back with and without arms, medium back with and without arms, designer, upholstered chairs, cafe chairs, computer chairs, school benches, center tables and trolleys, dining tables (oval, rectangular, square, round), stools (bath stools, square tools, rectangular tools), and baby chairs (rocking chairs, chairs with arms). Plastic furniture manufacturers mainly use the injection-molding process which involves heating plastic granules in a cylinder with an in-line reciprocating screw. The plastic granules are melted and injected into a cold mold, which lets melted plastic granules to take the mold's shape. This is one of the most important processes of the plastics processing industries. The injection-molding process is capable of making articles of considerable complexity at high production rates and low labor cost per unit among other benefits (Central Institute of Plastics Engineering and Technology, 2007). Auxiliary equipment includes granulators (scrap grinder), dryer units, loaders, blenders (mixers), mold temperature controllers, and robots (Bryce, 1999). Schematic depiction of the standard production process is given below (figure 1.1) to get a basic understanding of work flow / production process in molded plastic furniture manufacturing industries using injection-molding technique.

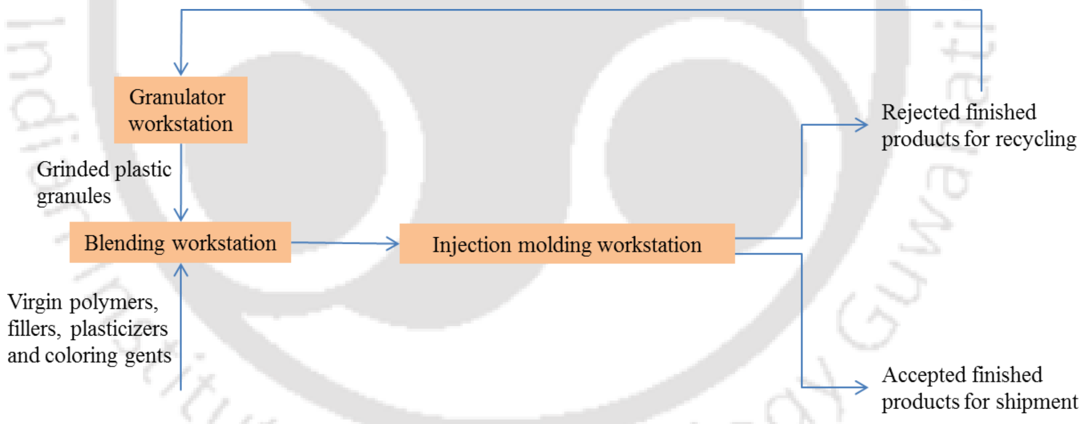


Figure 1.1 Standard production processes in molded plastic products manufacturing industries using injection-molding technique

1.5 Ergonomics

Ergonomics (or human factors) is the scientific discipline concerned with understanding the interactions among humans and other elements of a system, and applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance (International Ergonomics Association, 2014). Ergonomics / Human factor is concerned with the study of man-machine interfaces, primarily expected to optimize human wellbeing and to improve the all-round system performance (Chowdhury et al., 2012). Human factors / Ergonomics can make contributions to the design of all kinds of systems involving people like work systems and product / service systems (Dul et al., 2012). Practitioners of ergonomics and ergonomists deal with design and evaluation of tasks, jobs, products, environments and systems in order to make them compatible with the needs, abilities and limitations of humans (International Ergonomics Association, 2014). Physical ergonomics discusses the human anatomical, anthropometric, physiological and biomechanical characteristics (as they relate to physical compatibility) and areas of focus include working postures, material handling, repetitive movements, work related musculoskeletal disorders, workplace layout, safety and health (International Ergonomics Association, 2014). Cognitive ergonomics is related to mental processes, such as perception, memory, reasoning, and motor response, since they influence the interactions among humans and other elements of a system (International Ergonomics Association, 2014).

1.6 Indian Micro Small and Medium Enterprises: An ergonomics perspective

Micro Small and Medium Enterprises (MSMEs) has been acknowledged as the main cause of economic growth and for enhancing equitable development with its employment potential at low capital cost in India (Lal, 2005). More than 95% of industries are under MSMEs category in India (Mehta, 2014). MSMEs contribute about 45 per cent of the manufacturing output and 40 per cent of the total exports of India in terms of value, and employ nearly 595 lakh persons in over 261 lakh enterprises apart from producing over 6000 products ranging from traditional to high-tech items (Government of India, 2011-2012). Further, it is also reported that 67.10% of the enterprises in the registered MSMEs sector are engaged in manufacturing, whereas 16.78% of the enterprises were engaged in the services activities while the rest (16.13%) of the enterprises are engaged in repairing and maintenance activities (Government of India, 2011-2012). Indian MSMEs in the manufacturing sector is offering employment to a significant number of people. Ergonomics and human factors form a critical issue, as MSMEs in the manufacturing sector are labor intensive (Mehta, 2014). It is reported that health and safety issues of workers in

MSMEs are overlooked or neglected due lack of motivation, awareness and financial resources even though factory owners were concerned about the health and safety of workers (Mehta, 2014). Researchers have cited the existence of risk factors like the occurrence of musculoskeletal symptoms / disorders among workers in small and medium sectors in India (Joshi et al., 2001; Rai et al., 2012; Singh, 2012). The long term financial benefits of improving safety standards in MSMEs are overtaken by short term benefits of reducing costs, increasing production and profits (Mehta, 2014). Investigations focusing on quick, practical and demonstrative solutions / results (which may be easily be implemented with minimum or no investment costs) will benefit MSMEs as conventional mode of design intervention through design consultancy and training would not be affordable and also due to the nature of business of the Indian MSMEs (Mehta, 2014). Properly designed workstations, tools and equipment which are contextual and appropriate from an ergonomics perspective, is the first step towards developing effective health and safety management systems in Indian MSMEs (Mehta, 2014). Context specific design interventions should be attempted in order to reduce ergonomic risk factors and improve productivity (Chakrabarti & Bhattachheriya, 2012; Pandit et al., 2013).

1.7 Indian durable goods manufacturing sector: Occupational ergonomics perspective

Manufacturing denotes the process of converting raw materials, components or parts into finished goods in order to meet the customer's expectations or specifications. Durable goods manufacturing sector is predominantly characterized by the presence of man, equipment, tools and work place arrangements. It is very much understandable that in a labor intensive country like India, where focus is on increasing employment opportunities of a mammoth population, the discipline of ergonomics should be gladly received and applied for optimizing human-machine interaction for enhanced safety, comfort and wellbeing of workers in the durable goods manufacturing sector and for increasing the efficiency and productivity of work system. Investigations from an ergonomics perspective has been performed in Indian durable goods manufacturing industries like small scale casting (Singh, 2012), copper alloy foundry shop (Pareek et al., 2012), brick manufacturing (Pandey and Vats, 2012), assembly workstation in a welding shop (Shinde and Jadhav, 2012), welding workstation in a small scale tractor trolley manufacturing (Agrawal et al., 2011), small scale forging firms (Singh, 2010), foundries (Mohan et al., 2008; Kundu et al., 2005), cast house operations (Kumar and Das, 2012), Steel plant (Pachal et al., 2005; Pachal, 2014), electroplating of automobile parts (Jyothi and Johar, 2013), lock manufacturing (Muzammil et al., 2005), structural shop in steel factory (Pachal and Sastri, 2000), welding work (iron works, steel industries, etc.) (Chaudhary et al., 2012), steel plant (Ray and Tewari, 2012 a; Ray and Tewari, 2012 b), hot metal and glass factories (Sen, 1993), compatibility of controls in electric overhead cranes in a heavy engineering factory (Sen and Das, 2000), small scale aluminum casting works (Biswas et al., 2012), casting industry (Singh, 2012), glass manufacturing unit (Bhanarkar et al., 2005), electronic component manufacturing (Fernandez and Uppugonduri, 1992), small scale steel manufacturing (Chohan and Bilga, 2011), pedestal oil-lamp manufacturing (Senthil and Vadivel, 2012), glass manufacturing (Srivastava et al., 2000), potter industry (Pal et al., 2009), forging industry (Singh et al., 2009 a, b), modern workshop consisting of ordinary and computer integrated CNC machines (Maitra and Banerjee, 2014), transformer manufacturing industry (Wanave and Bhadke, 2014) and pump assembly work (Sekaran et al., 2014; Nishanth et al., 2014). Ignorance towards ergonomics, the science of human–machine compatibility is noticeable across all industries in Indian scenario. It is seen that limited efforts have been taken to investigate ergonomics aspects in the manufacturing shop-floor (Sanjog et al., 2013). There is scarcity of field studies in industrial ergonomics research (Singh et al., 2014). Ergonomic aspects are not given much thought while installing and commissioning majority of production units (large, medium, small, and micro) in India (Sanjog et al., 2013). As a result, durable goods manufacturing industries in India are far from human centric, thus affecting the workers' well-being (Sanjog et al., 2013). India is taking various efforts to improve its manufacturing sector through various initiatives. The focus in India is shifting towards a labor intensive manufacturing sector with the aim to make India a global manufacturing hub through the ambitious national campaign called 'Make in India' (Mehta, 2014). Such initiatives are expected to increase employment in manufacturing sector to 100 million workers by year 2025 (McCormack, 2011) and this forecast deserves to be taken notice by the practitioners / researchers, of the ergonomics discipline in India.

1.8 Need justification for investigations from an ergonomics perspective in the plastic processing sector of North East India

Assam is the largest economy of the North Eastern region of India mainly due to availability of good natural resources (oil and gas, coal, rubber, tea and minerals like granite, limestone and kaolin) and infrastructural facilities. The ideal geographical location makes Assam the gateway (for trade purposes) to the entire North East India, neighboring countries like China, Bangladesh, Nepal, Bhutan and Association of Southeast Asian Nations (ASEAN). The Micro Small and Medium Enterprise (MSME) Act 2006 (Chaturvedi, 2006) and North-East Industrial and Investment Promotion Policy (NEIIPP), 2007 (Prasad, 2007) implemented by Government of India, and the Industrial and Investment policy of Assam, Government of Assam (Das, 2014) provide a whole lot of incentives for entrepreneurs / business houses to set up industries as well as to expand the existing ones. The completion of Assam gas cracker project named Brahamaputra Cracker and Polymer Limited (a joint venture between Gas Authority of India Limited, Oil India Limited, Numaligarh Refinery Limited and Government of Assam) with Gas Authority of India Limited being given exclusive rights to handle distribution and marketing of Brahmaputra Cracker and Polymer Ltd (BCPL) polymer grades (Brahmaputra Cracker and Polymer Limited, 2014) is being eager eagerly looked forward by the plastic processing industries. The Assam Gas Cracker Project (Brahmaputra Cracker and Polymer Ltd) for producing High Density Polyethylene (HDPE) / Linear Low Density Polyethylene (LLDPE) and Polypropylene (from resources available in Assam) is expected to supply huge intermediate feedstock for further processing in a lot of downstream polymer units in Assam (Das, 2014). Government of Assam is planning to build a 'Plastic Park' near the project site which is expected to give rise to numerous plastic processing units and is also estimated to generate employment for 1, 00, 000 people (Central Institute of Plastics Engineering and Technology, 2010) and increased plastic processing activities throughout the State of Assam and the entire North Eastern region of India (Assam Industrial Development Corporation Limited, 2010). As a testimony for claims of increased employment generation, the case of Haldia Petro chemicals Limited (HPL) in the state of West Bengal in India is worth mentioning. HPL has led to industrial resurgence and economic growth in the region by giving more thrust to investments in downstream processing industries thereby generating huge employment opportunities for skilled and unskilled workers (Haldia Petrochemicals Limited, 2014). It is claimed that HPL was instrumental in the emergence of more than 500 downstream processing industries in West Bengal with a capacity to process more than 3,50,000 Tonnes per Annum (TPA) of polymers and subsequent generation of more than 1,50,000 employment opportunities in the process (Haldia Petrochemicals Limited, 2014). The same may be replicated in the State of Assam with a substantial increase in downstream plastic processing industries and generation of huge employment due to the expected commissioning of Brahmaputra Cracker and Polymer Limited.

Therefore in this context which promises definite growth of plastic processing in India, especially in the state of Assam, entire North Eastern region of India and subsequently increased number of people expected to be employed in this sector, shop-floor workstation investigations from an ergonomics perspectives in the existing plastic processing industries is deemed necessary. Research outcomes are sure to benefit the management and labor force of both the existing and the anticipated plastic processing industry in the state of Assam and the entire North Eastern region of India. Such an effort will definitely help enterprises wishing to set up new manufacturing units to proactively implement ergonomics in workstation designs, thus deriving benefits for all the stake holders.

1.9 Research gap

Following literature review, it is observed that there is no reported study on investigations concerning the workstation design and layout design of shop-floor with respect to small and medium scale injection-molded plastic furniture manufacturing industries in India. Investigations from ergonomics perspectives have been attempted in foundries, steel factories, welding shops in small scale industries, electroplating industries, glass factories, automotive and electronic component manufacturing, transformer manufacturing and pump assembly works, lock manufacturing, pedestal oil lamp manufacturing, oil and jute mills, sheet metal, cricket bat and zarda manufacturing, etc. (Sanjog et al., 2013). Hence there is an urgent need to investigate the current occupational health scenario, with respect to working posture, workstation design, work shift duration, indoor environment and layout in the shop-floor of the small and medium scale injection-molding plastic furniture manufacturing industries in India.

1.10 Aim of the research work

The research work aims to investigate the shop-floor working conditions in workstations of the Indian small and medium scale injection-molded plastic furniture manufacturing industries in Assam (a north-eastern state of India) and propose design interventions towards improving shop-floor working conditions from an ergonomics perspective.

1.11 Objectives of the research work

The following objectives were framed in order to achieve the aim of the research work.

7. Investigate the occurrence of awkward working postures and prevalence of symptoms of musculoskeletal ailments among shop-floor workers.
8. Assess the contributing role of workstation design (WD), working postures (WP) and work shift duration (WSD) towards symptoms of musculoskeletal ailments (SMA) and to find out the inter-relationships among all these factors.
9. Assess the hand grip strength before and after work for identifying the susceptibility of shop-floor workers for developing upper limb body part musculoskeletal disorder in due course of time.
10. Ergonomic assessment shop-floor workstations for identifying and estimating the extent of various risk factors (physical, psychosocial and subjective work load) and proposing design interventions, if required.
11. Investigate important indoor environmental parameters from a physical ergonomics perspective for proposing context specific recommendations, if required.
12. Investigate shop-floor layout design practices from physical and environmental ergonomics aspects for proposing context specific recommendations, if required.

1.12 Hypotheses

Factory visits were made initially to observe and understand the prevailing working conditions. After review of literature and discussions with supervisors / managers, the following three hypotheses were formulated for ensuring a proper direction to the research work.

1. **H_1** - Awkward postures, improper workstation design and prolonged work shift duration in the shop-floor of the Indian small and medium scale injection-molded plastic furniture manufacturing industries are significantly contributing (stand-alone / cumulative) to the incidence of symptoms of musculoskeletal ailments among workers in the shop-floor.
2. **H_2** - Ergonomic design intervention in terms of modifications of workstation accessories might be a definite solution for avoiding awkward posture in the shop-floor of the Indian small and medium scale injection-molded plastic furniture manufacturing industries.
3. **H_3** - Redesign of shop-floor layout and improvement in the physical work environment (air movement, temperature, relative humidity, illumination and noise level) is crucial for humanizing working conditions in the shop-floor of the Indian small and medium scale injection-molded plastic furniture manufacturing industries.

1.13 Flow of work

The thesis report has been divided into eight chapters depending on the flow of research work. The outline of hypothesis and objectives addressed in the respective chapters is shown in the following table 1.2.

Table 1.2

Hypothesis and objectives distributed in various chapters

Hypothesis	Objectives	Chapter
1. Awkward postures, improper workstation design and prolonged work shift duration in the shop-floor of the Indian small and medium scale injection-molded plastic furniture manufacturing industries are significantly contributing (stand-alone / cumulative) to the incidence of the symptoms of musculoskeletal ailments among workers in the shop-floor.	1. Investigate the occurrence of awkward working postures and prevalence of symptoms of musculoskeletal ailments among shop-floor workers. 2. Assess the contributing role of workstation design (WD), working postures (WP) and work shift duration (WSD) towards symptoms of musculoskeletal ailments (SMA) and to find out the inter-relationships among all these factors. 3. Assess the hand grip strength before and after work for identifying the susceptibility of shop-floor workers for developing upper limb body part musculoskeletal disorder in due course of time.	II, III
2. Ergonomic design intervention in terms of modifications of workstation accessories might be a definite solution for avoiding awkward posture in the shop-floor of the Indian small and medium scale injection-molded plastic furniture manufacturing industries.	4. Ergonomic assessment shop-floor workstations for identifying and estimating the extent of various risk factors (physical, psychosocial and subjective work load) and proposing design interventions, if required.	IV
3. Redesign of shop-floor layout and improvement in the physical work environment (air movement, temperature, relative humidity, illumination and noise level) is crucial for humanizing working conditions in the shop-floor of the Indian small and medium scale injection-molded plastic furniture manufacturing industries.	5. Investigate important indoor environmental parameters from a physical ergonomics perspective for proposing context specific recommendations, if required. 6. Investigate shop-floor layout design practices from physical and environmental ergonomics aspects for proposing context specific recommendations, if required.	V, VI, VII

Following is a brief summary of the subject matter presented in each chapter.

1.13.1 Chapter I (present chapter)

Topic: Introduction

Chapter I focused on highlighting the growth trends and prospects of global petrochemical industry; Indian plastic industry; Indian plastic processing industries and also described about the injection molded plastic furniture manufacturing industries. The relevance of 'Ergonomics' in micro, small and medium enterprises in the Indian durable goods manufacturing sector was discussed and the need for conducting investigations from an ergonomics perspective in the Indian plastic processing industries was emphasized. The research gap, aim of present research endeavor, objectives towards achieving the aim, hypotheses and flow of the research work is also given.

1.13.2 Chapter II

Topic: Musculoskeletal ailments in Indian injection-molded plastic furniture manufacturing shop-floor: Mediating role of work shift duration

Chapter II is related to investigating the occurrence of awkward working postures and consequent prevalence of symptoms of musculoskeletal ailments among shop-floor workers of Indian small and medium scale injection-molded plastic furniture manufacturing factories. Attempt has also been made to assess the contributing role of Workstation Design (WD), Working Postures (WP) and Work Shift Duration (WSD) towards the occurrence of Symptoms of Musculoskeletal Ailments (SMA) and to find out the inter-relationships among all these factors. Direct observation aided by photography helped to observe working methods, postures and design of workstations. Standardized Nordic questionnaire and postural assessment tools (Ovako Working Posture Analysis System and Rapid Entire Body Assessment) were employed to evaluate the prevalence of SMA and awkward WP respectively. Correlation and regression statistics were used to establish the mediating role of WSD in determining SMA. Awkward WP, prolonged WSD and bad WD were established as the significant risk factors for the high prevalence of SMA among shop-floor workers. Prevalence of SMA was found to be significantly ($p < 0.05$) higher for shop-floor workers in comparison with the employees in administrative and supervisory occupations. The influence of WP and WD on SMA was found to be significantly ($p < 0.05$) mediated through WSD. It has been established through statistical modeling that occurrence of SMA due to awkward WP and bad WD; is exacerbated if WSD is longer. Findings presented in chapter II would help in formulating ergonomic intervention strategies and proposing guidelines for eliminating symptoms of musculoskeletal ailments in shop-floor of the Indian small and medium scale injection-molded plastic furniture manufacturing industries.

1.13.3 Chapter III

Topic: Reduction of hand grip strength as an indicator towards discomfort of upper body extremities

Aim of the work mentioned in Chapter III is to assess the hand grip strength before and after work among shop-floor workers in injection-molded plastic furniture manufacturing factories. Hand grip strength dynamometer was used in the present study. Observations revealed significant difference / reduction in hand grip strength before and after work in both the hands among shop-floor workers. Reduction in hand grip strength may indicate the likelihood of shop-floor workers developing upper limb musculoskeletal disorders in due course of time. Reduction in hand grip strength may also be due to muscle fatigue. Hence, investigations focused on design interventions should be initiated in the Indian small and medium scale injection-molded plastic furniture manufacturing industries towards realizing human centric production systems.

1.13.4 Chapter IV

Topic: Workstation design interventions in shop-floor of injection-molded plastic furniture manufacturing industries

Investigations pertaining to workstation designs and work activities from an ergonomics perspective are less reported from the manufacturing shop-floor of Industrially Developing Countries (IDCs) like India. Less automation, prevalence of manual labor, locally designed workplace fixtures are usually observed in the Indian plastic processing industry which is highly fragmented; comprising of Micro Small and Medium Enterprises (MSMEs). Research work presented in Chapter IV aims to identify physical, psychosocial and subjective workload risk factors in blending, granulator and injection-molding workstations of existing small and medium scale injection-molded plastic furniture manufacturing industries and propose context specific design interventions. An innovative research methodology adopting a combination of questionnaire study, postural assessment tools, statistical analysis, work study, digital human modeling and simulation is utilized. Prevailing poor working postures was found to be largely influenced by workstation design and work methods. Research outcome presented in chapter IV towards redesign of workstation and subsequent modification of work methods considering demographic constraints and in accordance with recommended guidelines enabled significant downgrading the ergonomic risk perception of operational postures.

1.13.5 Chapter V

Topic: Indoor physical work environment: An ergonomics perspective

Work in the contemporary era is predominantly performed indoors. Indoor physical environmental factors (air movement, temperature, relative humidity, illumination and noise level) affect the performance of humans. Generally due consideration is not given to physical environmental aspects while designing individual workstation / workplace / facilities in an organization / industry. Keeping this scenario in mind it was felt that ample information in a consolidated form pertaining to basic indoor environmental parameters will definitely help managers, supervisors, engineers, designers and entrepreneurs to become conscious and take an effort towards implementation of recommendations adopted and proposed by scientific community / organizations for facilities layout planning. Indian standards are moderately addressed to help readers visualize the role of country specific organizations in promoting the development of standardization in agreement with international bodies. National institutions help in evolving strategies for formulation and accordingly recognition of standards in their respective countries. Research work presented in chapter V strives to collect, segregate and arrange needed information to represent an appropriate knowledge body towards investigating the indoor occupational environment of small and medium scale injection-molded plastic furniture manufacturing shop-floor.

1.13.6 Chapter VI

Topic: Indoor occupational environment investigations in the shop-floor of injection-molded plastic furniture manufacturing factories of North East India

Indoor work environment parameters like temperature, lighting and noise play a significant role in maintaining the workers' well-being besides ensuring good working conditions. Investigations pertaining to indoor work environment from an occupational health perspective in plastic processing industry are scarcely reported from industrially developing countries like India. Chapter VI deals with investigations pertaining to important indoor work environmental parameters prevailing in workstations of small and medium scale injection-molded plastic furniture manufacturing shop-floor. Comparisons of prevailing conditions with guidelines specified by scientific organizations and researchers indicate the need for implementing context specific corrective actions. Context specific suggestions are also proposed for improving indoor work environment.

1.13.7 Chapter VII

Topic: Redesign of small and medium scale injection molded plastic furniture manufacturing shop floor: Physical and environmental ergonomics aspects

Small and medium manufacturing enterprises have its own industry specific machines arranged in the shop-floor for manufacturing finished goods. Investigations pertaining to shop-floor layout designs from ergonomics and indoor environment perspective have not been performed in the Indian small and medium scale injection-molded plastic furniture manufacturing industries till date. Investigations pertaining to shop-floor layout design practices in existing small and medium scale injection-molded plastic furniture manufacturing industries in order to develop context specific guidelines based on ergonomics and indoor environment perspectives are given in chapter VII. Factories were visited for studying the existing shop-floor layout designs. The prevailing layout designs were evaluated by comparison with guidelines proposed by various researchers and scientific organizations. It was observed that ergonomics and indoor environmental factors were not considered while designing shop-floor layouts in small and medium scale injection-molded plastic furniture manufacturing industries. Problems in prevailing layouts have been highlighted. Context specific guidelines from published literature have been emphasized. A conceptual shop-floor layout was developed incorporating guidelines. Virtual representation of the conceptual shop-floor layout was rendered. Research outcomes mentioned in this chapter will be immensely beneficial for the Indian small and medium scale injection-molded plastic furniture manufacturing industries.

1.13.8 Chapter VIII

Topic: General discussion and conclusion of the overall thesis

Discussions mainly pertain to lack of ergonomics research and application in Indian durable goods manufacturing sector, expected growth of plastic processing industries in North East India, the need for research initiatives in the Indian plastic processing sector from ergonomics perspectives, injection-molded plastic furniture manufacturing industries, selection of factories for conducting research, research methodology adopted in present research work, salient findings in the shop-floor workstations, mitigation of risk factors: in the context of small and medium scale injection-molding plastic furniture manufacturing industry shop-floor workstations, scope for increased productivity through design interventions, harmony of the research initiative and proposals with the policies of Government of India from ergonomics perspectives, contribution of the research work and feedback from production managers / supervisors. Further, the conclusion along with scope for further studies and limitations of the present research work are also mentioned.

Chapter II

Musculoskeletal ailments in Indian injection-molded plastic furniture manufacturing shop-floor: Mediating role of work shift duration

Abstract

The present chapter aims to investigate the occurrence of awkward working postures and the consequent prevalence of the Symptoms of Musculoskeletal Ailments (SMA) among the shop floor workers. An attempt has also been made to assess the contributing role of Workstation Design (WD), Working Postures (WP) and Work Shift Duration (WSD) concerning symptoms of musculoskeletal ailments and to find out the inter-relationships among all these factors. Direct observation aided by photography helped to observe working methods, postures and the design of workstations. The prevalence of SMA was evaluated using Standardized Nordic Questionnaire and awkward WP by postural assessment tools like Ovako Working posture Analysis System (OWAS) and Rapid Entire Body Assessment (REBA). SMA was significantly ($p < 0.001$) higher for shop-floor workers compared to administrative and supervisory employees. Mediation statistics (using correlation and regression) was employed to analyze the stand-alone / cumulative impact(s) of WP, WD and WSD in determining SMA. Awkward WP, prolonged WSD and bad WD were established as the significant risk factors for higher prevalence of SMA for shop-floor workers. Influence of WP and WD on SMA was found to be significantly ($p < 0.05$) mediated through WSD. It was established through statistical modeling that occurrence of SMA due to awkward WP and bad WD is further exacerbated if WSD is prolonged. These findings would have constructive contributions in framing ergonomic intervention strategies and articulating methodological stipulations for work design to dwindle the SMA in shop-floor workers of the Indian small and medium scale injection-molded plastic furniture manufacturing factories.

2.1 Introduction

Ensuring and promoting safe and healthy working conditions is the main aim of ergonomics; the science dealing with the interactions among human, machine and the surrounding environment. Physical ergonomics deal with human anatomical, anthropometric, physiological and biomechanical aspects as they relate to physical activity; whereas cognitive ergonomics emphasizes on issues like perception, memory, reasoning and motor response (International Ergonomics Association, 2000). Interactions between human and the industrial working environment create challenging problems, reportedly increasing during the last few years, especially in the manufacturing systems scenario (Cimino et al., 2009).

Musculoskeletal disorders are reported to be the most prevalent form of occupational hazards among the majority of industrialized nations (Whysall et al., 2006). Globalization, along with rapid industrial growth, has caused the emergence of occupational health related issues in developing countries, including India (Saiyed and Tiwari, 2004). Occupational health issues are indeed prevalent in India across a wide spectrum of professions. Physical risk factors have been reported from India in various durable goods manufacturing industries like foundries, steel factories, welding shops in small scale industries, electroplating industries, glass factories, electronic component manufacturing, lock manufacturing, pedestal oil lamp manufacturing, etc. (Sanjog et al., 2013) and also in other unorganized sectors (Wani and Jaiswal, 2011; Das and Gangopadhyay, 2011). Ergonomists and occupational health researchers have highlighted multiple issues (awkward working postures, repetitive activities, manual heavy load handling etc.,) leading to occupational hazards among the workers of Micro, Small and Medium Enterprises (MSMEs) located in India (Rai et al., 2012). Though the symptoms of musculoskeletal ailments (SMA) are widely noticeable in various industrial sectors, occupational health related issues in Indian plastic processing industries have hardly been reported.

Plastic processing industries are extremely fragmented consisting of MSMEs offering enormous employment opportunities (Central Institute of Plastics Engineering and Technology, 2010). Petrochemical projects are catalyzing the establishment of plastic processing units (Assam Industrial Development Corporation Limited, 2010; Haldia Petrochemicals Limited, 2013). With the conspicuously growing numbers of small and medium scale plastic processing industries in India, evaluating the extent of the prevailing symptoms of musculoskeletal ailments has been identified as the need-of-the-hour. This would help in formulating guidelines and strategies in implementing ergonomic interventions which can be stipulated for the forthcoming industries. This piece of work therefore attempts to examine the contributing role of workstation design (WD), working postures (WP) and work shift duration (WSD) on the symptoms of musculoskeletal ailments (SMA) and extrapolate their interdependence (if there be any). Before starting the study, consent of participants was duly obtained by completing the 'consent form'. The whole data collection was performed in accordance with Helsinki protocol (World Medical Association of Helsinki, 2001).

2.2 Subjective assessment tools to assess symptoms of musculoskeletal ailments

Techniques involving self-reporting of musculoskeletal discomfort are widely used and generally accepted to evaluate ergonomic interventions or as a screening tool to detect exposures to workplace physical stressors (Sauter et al., 2005). Research has established the fact that NIOSH surveys, University of Michigan Upper Extremity Questionnaire (UMUEQ) and Standardized Nordic Questionnaire (SNQ) **(Appendix I)** were found to be sensitive to a wide range of physical stressors across many occupations have the capability to predict the musculoskeletal disorders in objective terms (Sauter et al., 2005).

The University of Michigan Upper Extremity Questionnaire (UMUEQ) is a 15-page, self-administered instrument designed for epidemiologic studies of workers and it includes a series questions relating to symptoms in three body regions, namely, neck / shoulder / upper arm, elbow / forearm, and wrist / hand / finger apart from questions related to demographic items and medical history (including exercise) (Salerno et al., 2001). The Cornell Musculoskeletal Discomfort Questionnaires are suspect in the case that it does not assess if the musculoskeletal discomfort is work-related and one of the main limitations is the lack of clinical validity testing for it specifically and the fact that it is primarily developed for use in upper body disorders (Telles et al., 2009). The standard version of the Dutch musculoskeletal Questionnaire (DMQ) consists of 9 pages consisting of around 25 questions per page, which should necessarily be filled in by the workers themselves (Hildebrandt, 2005). The DMQ includes questions related to background variables, tasks, musculoskeletal workloads, work pace and psychosocial working conditions, health and lifestyle, perceived bottlenecks and ideas for improvements (Hildebrandt, 2005). Some of the disadvantages of DMQ are the necessity of a reference group which may not be always available and the questionnaire being less applicable for smaller groups of workers (Hildebrandt, 2005).

Sauter et al. (2005) reports that test-retest reliability data on NIOSH discomfort surveys have not been previously reported, but cites a research work done by Lowe et al. (2001), where analysis of data from repeat administration (within 48 hours) showed encouraging findings in a sample of 89 office workers. In fact, major of studies using NIOSH musculoskeletal discomfort surveys covered poultry processing, beef processing, newspaper business, data processing / VDT activities, customer service, grocery warehouse, medical laboratory, textile manufacturing and clerical work where the combination of body maps and rating scales methodology was adopted to assess discomfort in multiple regions of body (Sauter et al., 2005).

On examination of the surveys used for identification of musculoskeletal symptoms, it was found that, widespread use of the SNQ and NIOSH surveys indicated their evidence of practical quality and it was also found that over three dozen studies in many countries since 1990 used SNQ or a variation of it (Sauter et al., 2005). SNQ and UMUEQ are in many respects similar to the discomfort surveys used by NIOSH (Sauter et al., 2005). Body maps used in many NIOSH studies have a very close resemblance to standardized diagram in the SNQ when compared to UMUEQ which employs verbal descriptors to distinguish body regions (Sauter et al., 2005).

The standardized Nordic questionnaire which can be self-administered or used in interviews is to be used for analysis of musculoskeletal symptoms in an ergonomic or occupational health context (Kuorinka et al., 1987; Andersson et al., 1987). The authors have stated that questionnaires like SNQ is supposed to be a diagnostic tool for evaluating MSD with respect to work environment, workstation and tool design and not meant for clinical diagnosis. In a study involving two different workstations exhibiting similar overall functions but having different job requirements in an industrial setting SNQ (Standardized Nordic Questionnaire) was found to be sensitive to identify different patterns of reported injuries (Deakin et al., 1994). Deakin and his colleagues argue that this type of approach (sensitiveness to two different workstation scenarios) is useful to identify problematic workstations and focus on workstation design, worker education and operator-machine interface. Further, they claim that this information can be utilized for implementing health and safety educational package for workers as well as for the implementation of administrative and/or engineering controls at these workstations. Significantly higher frequencies of musculoskeletal problems were reported when the questionnaire was administered as part of a focused study on musculoskeletal issues and work factors than when administered as part of a periodic general health examination (Andersson et al., 1987). SNQ is reported to be repeatable, sensitive and useful as a screening and surveillance tool (Crawford, 2007). The Nordic Questionnaire is widely used and validated (Kuorinka et al., 1987), and therefore it is possible to make comparison between different studies and this questionnaire method is a valuable tool for screening of symptoms / complaints in different occupational groups and further helps in identifying risky work environments (Arvidsson, 2008). Test retest reliability studies of SNQ described by Kuorinka et al. (1987) and Dickinson et al. (1992) highlight that one-week, 15 day, and 3-week retests in these studies resulted in identical response rates across questions ranging from 70 to 100%. The Nordic general questionnaire is a standardized instrument used to analyse musculoskeletal symptoms in an ergonomic or occupational health context (De Barros and Alexandre, 2003). Substantial reliability was reported in a study whose aim was to translate and adapt a version of the Nordic general questionnaire into Brazilian Portuguese and evaluate its reliability (De Barros and Alexandre, 2003). The Nordic musculoskeletal questionnaire, while questioning the prevalence of MSDs distanced itself using diagnostic labeling and simply asked for 'ache', 'pain' and 'discomfort' in nine body regions, and this approach enabled its application in a wide variety of workplaces by accommodating a large number of workers in a study quickly, cheaply and the extent of its application is a testimony to its acceptance by the work force as well as the national supervisory body for work-related health, safety and illness like Health and Safety Executive (HSE) (Dickinson et al., 1992). General limitations of questionnaire techniques also applies to the Nordic standardized questionnaire as the experience of the person who fills the questionnaire may affect the results and further the more recent and more serious MSDs are remembered better than the older and less serious ones (Kuorinka et al., 1987). One of the most important claims of the Nordic standardized musculoskeletal questionnaires is that it concentrates on symptoms mostly encountered in an occupational setting (Kuorinka et al. 1987; Dickinson et al. 1992).

2.3 Evaluation of working postures in industry

Posture is measured mostly using observational techniques in industry as they do not interfere with job, processes and further they do not require any additional equipment to be placed on the individual's body (which may cause operator discomfort and thus affect measured body angles) (Genaidy et al., 1994; Juul-Kristensen, et al., 1997). The visual perception of observational techniques comprise of two methods, namely direct observation on the job and determination of posture using replay of video tape (Genaidy et al., 1994). On job analysis should generally be adopted for checking suitability of workplace design, work methods, tools and equipment from ergonomics perspective (Johnson, 2003).

2.4 Postural evaluation tools for assessing the entire body

Rapid Entire Body Assessment (REBA) **(Appendix II)** postural evaluation tool was designed to be an event based tool applicable for investigating various types of unpredictable working postures found in health care and other service industry and till date it is the only postural analysis tool developed to assess animate load handling involving details about body posture, forces used, movement types / actions, repetition and coupling (Hignett and McAtamney, 2000; McAtamney and Hignett, 2005). REBA should be applied for postural analysis if the entire body is being used, posture is found to be static, dynamic, rapidly changing or unstable and the job involving frequently of infrequently handling animate or inanimate loads (McAtamney and Hignett, 2005). Working activities performed in manufacturing workstations in small and medium scale injection-molded plastic furniture manufacturing industries are characterized by dynamic and rapidly changing postures. The face validity of REBA has been established using numerous work postures from health care, manufacturing and electricity industries, and this tool has also been used for assessments pertaining to manual material handling operations (McAtamney and Hignett, 2005). Work activities performed in manufacturing workstations in small and medium scale injection-molded plastic furniture manufacturing industries are characterized by dynamic and rapidly changing postures. REBA is definitely a method to assess posture for risk of work related musculoskeletal disorders (WRMSDs) (Gangopadhyay et al., 2010).

Another practical method for analysis and control of poor working postures in industry is the Ovako Working Posture Analysis System (OWAS) (Karhu et al., 1977). OWAS **(Appendix III)** identifies the most common work postures for the back, arms, legs and weight of the load handled while the absence of neck and elbows / wrist assessments, no separation of right and left upper extremities, repetition and duration of sequential postures not considered are some of the limitations of this method (OWAS, 2009; Battini et al., 2011). OWAS method strictly advocates observations to be made in an actual work situation which includes making observations on an equal interval system (time interval between observations being 30 seconds or 60 seconds) preferably using video tapes for recording short work cycles (Matitila and Vilkki, 1998). Under OWAS methodology, the first classification of individual posture combinations point to the extent of risk of injury and other harmful effects caused by a particular posture (combination of postures of back, arms, legs and load handled) for the musculoskeletal system while the second classification (based on the time spent on different postures of each individual body part) evaluates the relative proportion of postures of back, arms, legs during the observation period (Matitila and Vilkki, 1998).

Postural evaluation tools like Quick Exposure Checklist (QEC) (Li and Buckle, 2005), Rapid Upper Limb Assessment (RULA) (McAtamney and Corlett, 2005), Strain Index (SI) (Moore and Garg, 1995; Moore and Vos, 2005) and Occupational Repetitive Action Method (OCRA) (Occhipinti and Colombini, 2005) are normally used for assessing the risks of upper limbs.

2.5 Nonprobability sampling and use of non-parametric statistics in the present research work

Descriptive statistics deals with the study of distributions of one variable whereas inferential statistical analysis deals with the various tests of significance for testing the hypothesis in order to determine whether with what validity data can be said to indicate some conclusion or conclusions. It is very important to note that the normality of the population distribution forms the basis for making statistical inferences about the sample drawn from the population (Kothari, 2011). Parametric tests are performed when the observations come from a normal population, sample size is large, and assumptions about population parameters like mean, variance etc. are found true before the tests are performed (Das and Das, 2004; Kothari, 2011). However, there may be situations in which the researcher cannot or do not want to make assumptions about population parameters (Kothari, 2011). Non-parametric tests do not make an assumption about the parameters of the population and do not make use of the parameters of the distribution, i.e. non-parametric or distribution free tests do not assume that a particular distribution is applicable or that a certain value is attached to a parameter of the population (Das and Das, 2004; Kothari, 2011). Non parametric tests normally assume only nominal or ordinal data whereas parametric tests require measurement equivalent to at least an interval scale (Kothari, 2011). Parametric tests cannot be applied to ordinal or nominal scale data but non-parametric tests do not suffer from any such limitations (Kothari, 2011). There is a growing use of non-parametric tests in situations where the normality assumption is open to doubt (Kothari, 2011).

2.6 Sample design details pertaining to nonprobability sampling

Different forms of sampling include probability sampling, non-probability sampling, convenience sampling, judgmental sampling, simple random sampling, systematic sampling, stratified sampling, cluster sampling and area sampling, quota sampling, multistage sampling and sequential sampling.

The following are some of the facts relating to the use of non-probability sampling design as given by Kothari, (2011)

- Increasing the sample size increases cost of collecting data and also enhances systematic bias.
- Probability sampling (every item of the universe has an equal chance of inclusion in the sample) is based on the concept of random selection whereas, non-probability sampling is non-random sampling on a representation basis.
- The deliberate sampling method involves purposive or deliberate selection of particular units of the universe for constituting a sample which represents the universe and the researchers' choice of items remains supreme.
- Non probability sampling which includes deliberate sampling is done for intensive study on the belief that the sample selected will be representative of

the entire universe and the judgment of the researcher is an important factor in this type of sampling design.

- Purposive sampling is considered more appropriate when the universe is small and a known characteristic of it is to be studied intensively.
- Sample designs other than simple random designs (probability sampling) may be considered better in real life situations.
- In a situation where random sampling is not possible, then sampling design other than random sampling is necessarily used.
- Non probability sampling design is adopted in small inquiries and researches by individuals because of the relative advantage of time and money.
- In non-probability sampling design sampling error cannot be estimated and the element of bias (great or small) is always present.

Deliberate sampling also known as purposive or non-probability sampling (selection of factories, workstations, questionnaire and workers) was adopted during this research work. Since sample size is not considerable and non-probability sampling method was appropriate for present research work, non-parametric statistical tests were used for statistical analysis.

2.7 Aim

To investigate the occurrence of awkward working postures and the consequent prevalence of symptoms of musculoskeletal ailments among shop-floor workers of Indian small and medium scale injection-molded plastic furniture manufacturing factories. Attempt has also been made to assess the contributing role of workstation design (WD), working postures (WP) and work shift duration (WSD) for the occurrence of the symptoms of musculoskeletal ailments (SMA) and to find out inter-relationships among all these factors (if there be any).

2.8 Study population and methods

2.8.1 Selection of factories, workstations and workers for survey

Seven injection-molded plastic furniture manufacturing factories (in small and medium sectors) located in the state of Assam, India were identified for the possibility of conducting research. However, permission was granted by the managements of four organizations to conduct ergonomic studies for their factories. Non-disclosure agreements regarding their identification compelled to keep them anonymous.

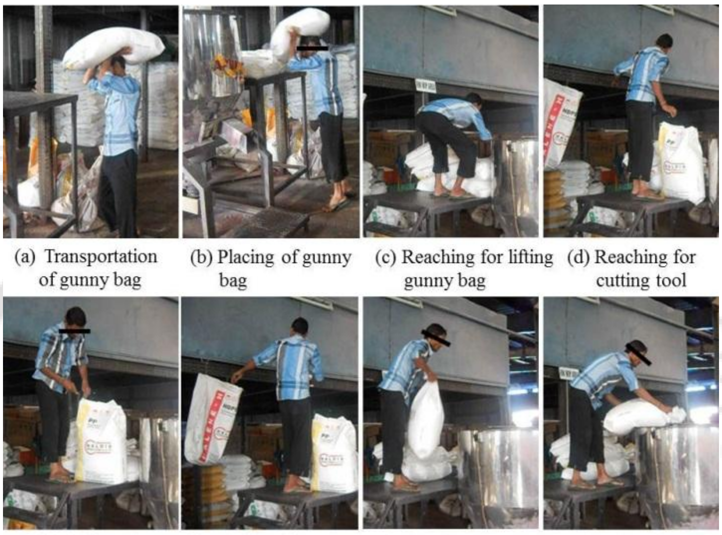
Three (03) shop-floor workstations, namely, blending (mixing), granulator (grinding / scrap grinder) and injection-molding were selected to assess the various physical risk factors leading to the occurrence of the symptoms of musculoskeletal ailments. Work schedule of six days a week and work shift duration of 8 and 12 hours was noticed among workers in the factories. Male workers were employed in the shop-floor workstations. Healthy adult male workers were selected as participants / responders as per the following pre-set inclusion criteria – similar age, weight, standing height, and work experience (minimum one to less than five years of uninterrupted work in the present occupation); and no medical record of any chronic disease. Workers with work experience of more than five years were rarely present in any of the factories, leading to their exclusion in order to maintain a narrow range of work experience.

Twenty-nine workers (29) from the blending workstations, ten (10) from the granulator workstations and forty-six (46) from the injection-molding workstations participated in the study. Workers in the shop-floor workstations were considered as the experimental group. Personal information (native state, dominant working hand, use of corrective lens for the eyes, formal training in ergonomics at the workplace, educational status, medical problems diagnosed by the physician, etc.) of the shop-floor workers was collected using a personal information questionnaire (adopted and modified from Ostrom, 1993; Engels et al., 1996; Chiu et al., 2002; Choobineh et al., 2004; Bhattacharyya, 2011) given in **Appendix IV** and gathered data has been presented in **Appendix V**. Fifteen (15) individuals with similar demographic characteristics, but involved in different activities (administrative and supervisory occupations), were selected to constitute the control group. None of the participants had any form of discomfort / pain / ache in any part of the body due to past accident / injury. Information regarding age and work experience was gathered by means of an interview, whereas weight and standing height were recorded by direct measurement.

2.8.2 Description of shop-floor workstations and associated work activities

2.8.2.1 Blending Workstation

Blending is done to mix polymers uniformly with additives like fillers, plasticizers, and coloring agents. The work activities observed in this workstation are illustrated in figure 2.1.



(a) Transportation of gunny bag; (b) Placing of gunny bag; (c) Reaching for lifting gunny bag; (d) Reaching for cutting tool; (e) Cutting open gunny bag; (f) Reaching for dropping cut thread; (g) Lifting gunny bag; (h) Conveying polymers

Figure 2.1 Postures adopted by workers during various activities in the blending workstation

2.8.2.2 Granulator workstation

Injection-molding process in plastic processing industry unavoidably produces defective parts and granulators are used to grind faulty finished products into sizes comparable to original virgin pellets for reuse in making finished products (Bryce 1999). Granulator is also used to grind rejected / defective finished goods as well as used plastic products sourced from the open market into plastic granules for reuse in the production process. Loading of products into granulator machines for grinding was performed manually in the workstations considered for investigations. Work activity in granulator workstation comprised of the operator taking one or two articles together from a stack, conveying the product(s) into the granulator and then waiting for the equipment to grind it. This process was repeated successively. The work activities observed in this workstation are illustrated in figure 2.2.

Figure 2.2 Postures adopted by workers during various activities in the granulator workstation

2.8.2.3 Injection-molding workstation

The injection-molding machine is used to melt plastic granules in order to facilitate their injection into the cold mold for manufacturing finished products. The work activities observed in this workstation are illustrated in figure 2.3.

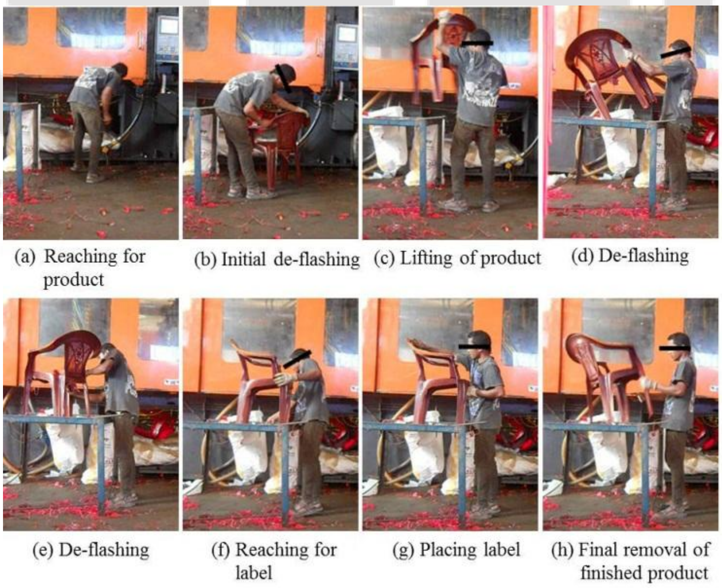


Figure 2.3 Postures adopted by workers during various activities in the injection-molding workstation

2.8.3 Study of symptoms of musculoskeletal ailments

The Standardized Nordic Questionnaire was used to investigate the prevalence of the symptoms of musculoskeletal ailments and identify the suffered body parts (Kuorinka et al., 1987). The procedure involved showing a body map to volunteers and recording the responses to various queries in the questionnaire. Incidences of fatigue, injury and accident were not assessed as they were beyond the scope of the stated purposes of this study.

2.8.4 Study of awkward working posture

The Ovako Working posture Analysis System (OWAS) is an internationally accepted method for analysis and control of poor working postures in the industry (Karhu et al., 1977). It analyzes the most common work postures for back, arms and legs including the weight of the load handled. OWAS technique was first employed to understand the overall scenario of the awkward postures during various activities. This technique lacks neck / elbows / wrist assessments and there is no distinct separation of right and left upper extremities (OWAS, 2009; Battini et al., 2011). So for drawing clear inferences, Rapid Entire Body Assessment (REBA) (Hignett and McAtamney, 2000) was used subsequently for postural assessment. REBA evaluates the manual material handling operations and the validity of REBA has been established using numerous work postures from health care, manufacturing, electricity industries, etc. (McAtamney and Hignett, 2005). The entire work cycle in each workstation was divided into different work elements (placing, lifting and cutting). Photographs of the workers performing different tasks (representing the major work elements) were taken from more than one viewpoint for clear observation of relative positions of the body segments. OWAS action categories for prevention of musculoskeletal disorders (table 2.1); REBA methodology for determination of risk level and action to be taken (table 2.2) were utilized as guidelines for categorizing the working postures.

Table 2.1

OWAS action categories

Action category (score)	Explanation
1	Normal and natural postures with no harmful effect on the musculoskeletal system - no action required
2	Postures with some harmful effect on the musculoskeletal system - Corrective actions required in near future
3	Postures have harmful effect on the musculoskeletal system - Corrective actions should be done as soon as possible
4	The load caused by these postures has a harmful effect in the musculoskeletal system - Corrective actions for improvement required immediately

(adopted from Mattila and Vikki, 1998)

Table 2.2

REBA action categories

Score	Risk level and action to be taken
1	negligible risk, no action necessary
2 or 3	low risk, change may be needed
4 to 7	medium risk, further investigation, change soon
8 to 10	high risk, investigate and implement change
11 +	very high risk, implement change

(adopted from Hignett and McAtamney, 2000)

2.8.5 Statistical techniques for data analysis

Inferential statistics helps to obtain conclusions regarding the source of data (Hoel, 1976). Sample sizes were small and the collected datasets did not follow the normal distribution in many instances. Hence, non-parametric statistics techniques which are used for small samples, nominal, ordinal and non-normal distributions (Das and Das, 2004) were used. Mann-Whitney U test, Chi square test, Correlation and Regression analysis were employed to analyze and interpret the collected data using SPSS v.20.0

(IBM, USA) software. Brief descriptions of the statistical methods used for investigations are given below.

2.8.5.1 Comparison of the demographic characteristics

Das and Das (2004) stated that the Mann-Whitney U test is used to test the significance of differences between unpaired observations of two independent groups of unequal sizes and may be applied for both continuous and discrete measurement variables. The significance of differences in age, weight, standing height and work experience between the individual groups (experimental vs. control) was evaluated using the Mann-Whitney U test.

2.8.5.2 Comparing the prevalence of symptoms of musculoskeletal ailments

Chi-square test is based on the analysis of frequencies for identifying whether an observed frequency distribution differs significantly from a proposed frequency distribution (Das and Das, 2004). The chi-square test was applied to investigate whether significant differences existed between the experimental and the control group with regard to the prevalence of the symptoms of musculoskeletal ailments. The number of workers suffering from the symptoms of musculoskeletal ailments in the experimental group and the control group were analyzed following a method (examining whether the occurrence of the symptoms of musculoskeletal ailments in the experimental group was higher than the control / comparison group) adopted by Gangopadhyay et al. (2007).

2.8.5.3 Investigating the association among working posture, work shift duration, workstation design and the symptoms of musculoskeletal ailments

The relationship between the variables may be quantitatively measured using correlation coefficients while regression coefficient is a prediction statistic used for assessing the average rate of change in the value of a criterion for unit changes in the value of a predictor (Das and Das, 2004). Categorical data of variables like working postures (satisfactory / unsatisfactory), workstation design (satisfactory / unsatisfactory) and work shift duration (8 hours / 12 hours) were utilized for correlation and regression statistics to quantify the relationships among those variables. In order to differentiate the categories of each variable, code ‘0’ and ‘1’ were used (Field, 2013).

2.8.5.4 Investigating the influence of working postures, work shift duration and workstation design on the symptoms of musculoskeletal ailments

Mediation statistics aims to identify the variable(s) through which the independent variable influences the dependent variable (Howell, 2010). The mediation path comprises of individually significant paths connecting the independent variable to the potential mediator which in turn is linked to the dependent variable (Howell, 2010). Work shift duration (independent variable) was hypothesized as the potential mediator for working posture (independent variable) and workstation design (independent variable) contributing to the symptoms of musculoskeletal ailments (dependent variable). Mediation is said to occur when the significant paths between the independent and dependent variables becomes insignificant or greatly reduced in the presence of the mediator (Howell, 2010). The regression coefficients and standard errors for the mediation pathways were calculated using appropriate methods given by Howell (2010). The Wald test, which helps in determining the statistical significance of each independent variable towards the model / prediction (Lund Research Limited, 2013) was used in the investigation of mediation pathways. Nagelkerke R Square values explain the variation in the dependent variable (Lund Research Limited, 2013). The dependent and independent variables in various levels (different models) are as follows.

Working posture, work shift duration and workstation design were considered as independent variables and the symptoms of musculoskeletal ailments as the dependent variable in Model - I (figure 2.4) through paths ‘a’, ‘b’, and ‘c’ respectively. Model - II (figure 2.4) has three paths designated as path ‘a’, ‘b’, and ‘c’. Work shift duration is the dependent variable and working posture is the independent variable in path ‘a’. Work shift duration is the independent variable and the dependent variable is the symptoms of musculoskeletal ailments in path ‘b’. Similarly, the dependent variable is the symptoms of musculoskeletal ailments while working posture is the independent variable in path ‘c’. Model - III (figure 2.4) also has three paths designated as path ‘a’, ‘b’, and ‘c’. Work shift duration is the dependent variable and workstation design is the independent variable in path ‘a’. Work shift duration is the independent variable and the dependent variable is the symptoms of musculoskeletal ailments in path ‘b’. Similarly, the dependent variable is the symptoms of musculoskeletal ailments while workstation design is the independent variable in path ‘c’. Model - IV (figure 2.4) has two paths designated as path ‘a’ and ‘b’. Working posture and workstation design are the independent variables while the dependent variable is the work shift duration in path ‘a’. The dependent variable is the symptoms of musculoskeletal ailments and the independent variables are working posture, workstation design and work shift duration in path ‘b’.

2.9 Results

2.9.1 Comparison of demographic characteristics

The total number of participants (including both control group and experimental groups) was 100. Comparison (using Mann Whitney U test) of the demographic variables (age, weight, standing height, work experience) between control and the experimental groups indicated that there were no significant differences except for the variable weight between the workers of the blending and the granulator workstations (table 1). This indicates that the participants in each of the experimental group as well as the control group were of similar age, weight, standing height and work experience.

Table 2.3

Characteristics of the workers / employees in the injection-molded plastic furniture manufacturing factories

Variables	Units	Experimental group						Control group		Comparisons (Mann Whitney U test)					
		Blending Workstation (BW) (n = 29)		Granulator Workstation (GW) (n = 10)		Injection Molding Workstation (IW) (n = 46)		Administrative and supervisory employees (CG) (n = 15)		BW Vs. CG	GW Vs. CG	IW Vs. CG	BW Vs. GW	BW Vs. IW	GW Vs. IW
		Mean	SD	Mean	SD	Mean	SD	Mean	SD						
Age	yrs.	26.7	4.3	27.1	2.5	25.1	3.3	25.4	2.5	NS	NS	NS	NS	NS	NS
Weight	kg	56.1	7.7	61.6	2.9	57.9	7.1	58.7	5.3	NS	NS	NS	*	NS	NS
Standing height	cm	159.4	18.9	164.7	6.1	165.5	6.3	162.7	7.4	NS	NS	NS	NS	NS	NS
Work Experience	yrs.	2.1	0.9	2.0	0.8	2.3	1.3	1.8	0.7	NS	NS	NS	NS	NS	NS

Legends: BW - Blending Workstation; CG – Control Group; GW - Granulator Workstation; IW – Injection-Molding Workstation; NS – no significant difference ($p > 0.05$); * – significant difference ($p \leq 0.05$).

2.9.2 Observations on the incidence of the symptoms of musculoskeletal ailments

The number of participants suffering from the symptoms of musculoskeletal ailments while working was 5 in the control group. In experimental groups the number of sufferers were 25, 10 and 43; in blending, granulator and injection-molding workstations respectively. The Chi square test revealed that the values of the experimental groups (combined) were significantly higher ($\chi2$ - 26.849; $P < 0.001$) compared to the values of the control group in terms of participants suffering from the symptoms of musculoskeletal ailments. The incidence of such symptoms across various body parts was also predominant for the experimental groups. The distribution of the incidence of symptoms (during the last 12 months) is shown in table 2.4.

Table 2.4

Numbers of participants (% of the total number in corresponding workstation) suffering from symptoms of musculoskeletal ailments in different body parts during the last 12 months

Body parts	Numbers of participants (% of the total number in corresponding workstation)			
	Experimental group			Control group
	Blending workstation (n=29)	Granulator workstation (n=10)	Injection-molding workstation (n=46)	Administration and supervisory employees (n=15)
Shoulder (right)	3 (10.3%)	0	5 (10.9%)	0
Shoulder (left)	1 (3.4%)	0	0	0
Shoulder (both)	20 (69.0%)	5 (50%)	26 (56.5%)	0
Elbow (right)	2 (6.9%)	0	3 (6.5%)	0
Elbow (Both)	21 (72.4%)	2 (20%)	6 (13.0%)	0
Wrist (right)	4 (13.8%)	2 (20%)	24 (52.2%)	0
Wrist (left)	2 (6.9%)	0	0	0
Wrist (both)	17 (58.6%)	5 (50%)	15 (32.6%)	0
Fingers (right)	0	0	2 (4.3%)	0
Upper back	1 (3.4%)	0	2 (4.3%)	1 (6.7%)
Low back	21 (72.4%)	8 (80%)	38 (82.6%)	2 (13.3%)
Knees (one/both)	18 (62.1%)	5 (50%)	16 (34.8%)	1 (6.7%)
Ankle (both)	0	0	3 (6.5%)	0
Hip (one/both)	0	4(40%)	0	0
Neck	0	0	0	2 (13.3%)

2.9.3 Working posture assessment

Although the activities of many workers were observed, the results tabulated (table 2.5) are based on the observations of an individual worker. Due to similar physical characteristics (insignificant difference in standing height) and work methods, all other workers adopted similar awkward postures while performing the same tasks. Therefore the data was representative in nature. The results of OWAS and REBA for an individual worker (shown in figures 2.1, 2.2 and 2.3) are presented in table 2.5.

Based on the postural risk and physical load on the musculoskeletal system, various action categories were formulated in the OWAS method (Matitila and Vilkki, 1998). These action categories ranged from '1' (no actions required) to '4' (corrective actions required immediately). Similarly, the REBA scoring system was based on the postural load of different body segments, the type of muscle activity (due to static, dynamic, rapidly changing or unstable postures) and the effect of coupling. In this posture evaluation technique, score '1' is assigned for negligible risk whereas score '11+' indicated a very high risk and immediate implementation of change (Hignett and McAtamney, 2000).

Table 2.5

Postural scores by using OWAS and REBA techniques in different shop-floor workstations

Posture (see figure 2.1, 2.2 and 2.3)	Blending workstation			Granulator workstation			Injection-molding workstation			Action category as per OWAS and REBA scores
	OWAS Score	REBA Score		OWAS Score	REBA Score		OWAS Score	REBA Score		
		Rt	Lt		Rt	Lt		Rt	Lt	
a	2	8	8	3	12	11	1	7	9	**OWAS**
b	2	9	9	1	2	7	2	6	8	Score 1 = No action required Score 2 = Corrective actions required in near future
c	4	12	12	3	12	11	1	3	8	Score 3 = Corrective actions should be done as soon as possible
d	1	6	7	1	6	4	1	3	6	Score 4 = Corrective actions for improvement required immediately
e	1	4	4	1	4	6	1	4	4	**REBA**
f	1	4	6	1	3	3	1	7	4	Score 1 = Negligible risk, no action necessary Score 2 or 3 = Low risk, change may be needed
g	3	8	8	2	5	5	1	7	2	Score 4 to 7 = Medium risk, further investigation, change soon
h	2	10	10	2	6	6	1	1	1	8 to 10 = high risk, investigate and implement change 11 + = very high risk, implement change

Legends: Rt – Right Body Side, Lt – Left Body Side; N.B: Alphabets (a, b, c, d, e, f, g and h) are the representative of postures shown in figures 2.1, 2.2 and 2.3.

Although OWAS and REBA postural load evaluation techniques are different in terms of associated body segments and scoring pattern, overall results observed from both the techniques (as in table 2.5) indicated that many of the postures were awkward in nature and required corrective measures. Due to the limitations in the OWAS technique few postures, which were actually unsafe, were not identified. The REBA technique helped in identification of those postures by considering the position of neck / elbows / wrist and the type of muscle activity (static / dynamic / coupling).

2.9.4 Association among working posture, work shift duration, workstation design and the symptoms of musculoskeletal ailments

The participants whose working postures when assessed by REBA and found to exhibit negligible risk or low risk scores (1 to 3) were grouped in the 'satisfactory working posture category'; whereas those determined by REBA to be medium, high or very high risk scores (4 to 11+) were grouped in the 'unsatisfactory working posture category'. The workers with satisfactory working postures were coded '0' while those with unsatisfactory working postures were coded '1' for statistical analysis. Workstation designs were subjectively judged as satisfactory or unsatisfactory based on a checklist adopted and compiled from Helander (1995) and MacLeod (2000). Ergonomic workstation design principles of physical demand; reachability; frequency and types of body part movements; discomfort in body parts; clearance; stability and balance of the body during work; task visibility; and physical compatibility of work accessories with the user were considered in that checklist. Satisfactory workstation designs were coded '0' while unsatisfactory workstation designs were coded '1'. Similarly, workers working on a work shift duration of 8 hours were given the code '0' while those working on 12 hours' work shift duration were coded '1'. Categorized WP (satisfactory, unsatisfactory), WSD (8 hours, 12 hours) and WD (satisfactory, unsatisfactory); and the number of participants in each category were considered in order to study the association of individual risk factors with the SMA (table 2.6).

Table 2.6

Prevalence, odds ratio and 95% Confidence Interval (CI) of the symptoms of musculoskeletal ailments for various risk factors

Risk Factors	Category	Prevalence (N)	Odds Ratio (OR)	95 % CI	Level of significance
Working Posture	Satisfactory	15	22.2	5.9 - 83.6	0.001
	Unsatisfactory	85			
Work Shift Duration	8 hours	19	72.8	15.6 - 339.6	0.001
	12 hours	81			
Workstation Design	Satisfactory	14	17.5	4.7 - 65.2	0.001
	Unsatisfactory	86			

WP and WD are associated with lower odds (effect size / strength of association) for SMA in comparison to work shift duration (table 2.6). Phi (nominal by nominal) correlation was calculated for ascertaining the relationships among SMA, WP, WD and WSD. Significant relationships were observed between each pair of variables (table 2.7).

Table 2.7

Correlations coefficient values between each pair of variables (working posture, work shift duration, workstation design and the symptoms of musculoskeletal ailments)

Parameters	WP	WSD	WD	SMA
WP	1	0.582*	0.960*	0.555*
WSD	0.582*	1	0.539*	0.731*
WD	0.960*	0.539*	1	0.508*
SMA	0.555*	0.731*	0.508*	1

Legends: * - Significant correlation; WP – working postures;
WSD – work shift duration; WD – workstation design;
SMA – symptoms of musculoskeletal ailments

It is observed that the correlation coefficient between WP and SMA ($r = 0.555$; $p < 0.001$) is less than the correlation coefficient between WSD and SMA ($r = 0.731$; $p < 0.001$); and also between WP and WSD ($r = 0.582$; $P < 0.001$). These special patterns of relationships fulfilled the criteria to postulate the mediation effect (Howell, 2010) of WSD on the relationship between WP and SMA (Sanjog et al., 2015 b).

Similarly, the correlation coefficient between WD and SMA ($r = 0.508$; $p < 0.001$) was less when compared to the correlation coefficient between WSD and SMA ($r = 0.731$; $P < 0.001$); and also between WD and WSD ($r = 0.539$; $P < 0.001$). This type of relationships among variables again fulfilled the criteria of mediation statistics (Howell, 2010). It was understood from these observations that WSD might have a mediation effect on the influence of WD upon SMA.

2.9.5 Influence of working postures, work shift duration and workstation design on the symptoms of musculoskeletal ailments

The mediation effect was studied using regression statistics. In step - I (table 2.8) simple binomial logistic regression analysis was performed by taking SMA as the dependent variable, while WP, WD and WSD were assigned as predictors separately. It was observed that WP was able to significantly ($p < 0.001$) predict 35.3 % change in SMA while WSD and WD were able to significantly ($p < 0.001$) predict 59.1 % and 29.9 % change in SMA respectively, as shown in table 2.8. The model for step - I is schematically represented in figure 2.4 as Model - I.

In step - II (table 2.8), binomial logistic regression was performed to predict SMA on the basis of two separate pairs of variables (WP and WSD being the first pair while the second pair consisted of WD and WSD) and to investigate the mediation effect of WSD. Binomial regression analysis using WP and WSD as predictors for SMA showed that WP and WSD together can predict 62.0 % of SMA. Similarly, WD and WSD when taken as the predictors for SMA were able to predict 61.2 % of the incidence of SMA. Models for step - II are schematically represented in figure 2.4 as Model - II and Model - III.

In step - III (table 2.8), binomial logistic regression was performed by keeping WP, WSD and WD as the predictors for the independent variable SMA. Here, it was observed that the effect of WP and / or WD on SMA was no longer significant in the presence of WSD in the predictor list. It was also observed that the three predictors (WP, WSD and WD) together can predict SMA by 62.4%. The model for step - III is schematically represented in figure 2.4 as Model - IV.

Table 2.8

Summary of mediation statistics

Step	Model	Variables	Regression coefficient B	Regression coefficient Std. Error	Wald value	Significance level	Nagelkerke R^2 value
I	I	Intercept	-0.693	0.548	1.602	0.206	0.353
		Working postures	3.104	0.675	21.143	0.000	
		Intercept	-1.030	0.521	3.906	0.048	0.591
		Work shift duration	4.288	0.786	29.769	0.000	
		Intercept	-0.588	0.558	1.111	0.292	0.299
		Workstation design	2.865	0.670	18.285	0.000	
II	II	Intercept	-1.817	0.779	5.440	0.020	0.620
		Working postures	1.547	0.921	2.823	0.093	
		Work shift duration	3.680	0.839	19.247	0.000	
	III	Intercept	-1.767	0.804	4.828	0.028	0.612
		Workstation design	1.334	0.938	2.025	0.155	
		Work shift duration	3.810	0.830	21.089	0.000	
III	IV	Intercept	1.728	0.792	4.765	0.029	0.624
		Working postures	20.947	40192.991	0.000	1.000	
		Work shift duration	3.654	0.841	18.866	0.000	
		Workstation design	-19.475	40192.991	0.000	1.000	

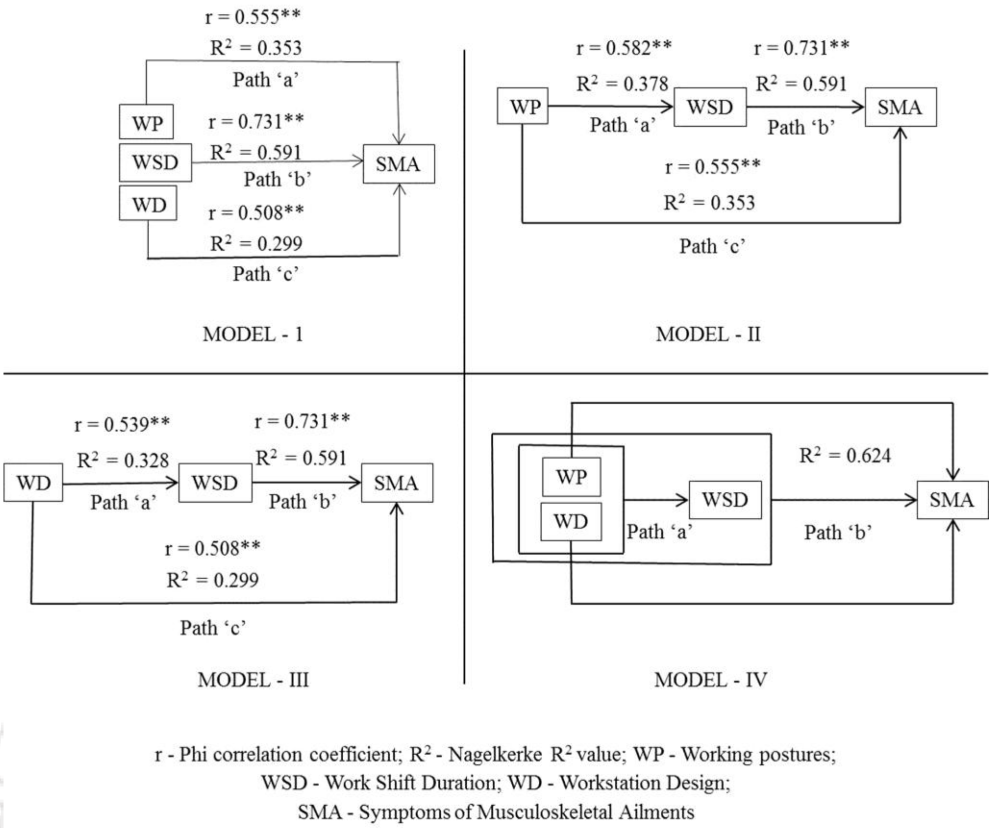


Figure 2.4 Schematic representations of mediation statistics

Regression coefficient for WP in model-II (B=1.547) is lower than in model-1 (B= 3.104) and regression coefficient for WD in the model- III (B=1.334) is lower than in model-1 (B= 2.865). This indicates the mediation effect of WSD upon influence of WP and WD on SMA.

The significance of the mediation path (WP-WSD-SMA) for the model 2 and mediation path (WD-WSD-SMA) for model III was calculated (table 2.9). In both cases, the significant mediation effect of WSD was observed. The significance of the mediation path [(WP & WD) →WSD→SMA] for model IV (figure 2.5) was also calculated. It was noticed that WSD significantly mediated the influence of WP and WD on SMA (table 2.9). Thus it was proved that WSD had a significant mediating role upon WP and WD in predicting SMA.

Table 2.9

Statistics of mediation pathways

Particulars	Model II	Model-III	Model-IV
Mediation path (calculated values)	WP→WSD→SMA	WD→WSD→SMA	(WP & WD) →WSD→SMA
Regression coefficient	14.047	13.134	43.027
Standard Error	3.887	3.786	6.273
Wald value	13.104	12.145	47.045
Significance level	$p < 0.05$	$p < 0.05$	$p < 0.05$

Legends: WP – working postures; WSD – work shift duration; WD – workstation design; SMA – symptoms of musculoskeletal ailments

2.10 Discussion

Symptoms of musculoskeletal ailments were observed among workers in the shop-floor workstations. **Thus the objective - 1 of the research work is accomplished.** The occurrence of the symptoms of musculoskeletal ailments (discomfort, pain and ache) during the work was significantly higher for the experimental group (blending, granulator, injection-molding workers) when compared with the control group. Although the participants of each of the experimental group were of similar characteristics (age, weight, standing height and work experience) as that of the control group (table 2.3); the higher prevalence of the symptoms of musculoskeletal ailments among the participants of the experimental groups (shop-floor workers) can be attributed to the differences in the occupational activities performed by them. The occupational activities were influenced by working posture, working methods, manual load handling and workstation design. It was observed that awkward working postures were very common (table 2.5) in experimental groups. Blending activities included manual lifting of gunny bags of 25 kg in weight. Activities in the granulator and injection-molding workstations comprised of manual handling of finished goods. Likewise activities in the injection-molding workstation were considerably fast-paced and extremely monotonous involving retrieval and de-flashing of finished goods. Awkward working postures, heavy manual material handling, rapid work pace, poor workstation design and inappropriate work methods contribute to the incidence of musculoskeletal disorders (Bridger, 2002; Corlett and Clark, 1995; Kroemer, 1997; Pheasant and Haslegrave, 2006). Similar observations have also been reported from plastic processing industry in developed countries (OhioBWC, 2008), as was evident in present findings too.

REBA (helpful in identifying the risk level and the urgency of taking remedial measures) may be taken as a guideline towards redesign or modification of workstation, work accessories, layout and the working method. Working postures were classified as satisfactory / unsatisfactory using REBA. The effect of postural conditions (static, repetitive) was taken care of during REBA scoring. REBA indicated very high, high and medium risk for various working postures in all the shop-floor workstations. Scores and action categories determined by the postural assessment tools might deviate to some extent if similar tasks were performed by workers having different body dimensions and working habits, apart from those workers shown in figures 2.1, 2.2 and 2.3. Without any doubt, it can therefore be interpreted from observations that the shop-floor workers are exposed to frequent awkward working postures which are harmful from an occupational health perspective (Sanjog et al., 2015 b).

After calculating the odd ratios (table 2.6); WP, WSD and WD were identified as the significant risk factors associated with SMA. Strength of association between WSD and SMA was found to be higher when compared with WP and WD. Significant correlations (table 2.7) were also found between risk factors (WP, WSD and WD) and SMA which indicated that all risk factors were responsible for the occurrence of symptoms of musculoskeletal ailments (Sanjog et al., 2015 b).

Following the interpretation of the correlation coefficients among variables (WP, WSD, WD and SMA), it was assumed that there might be a mediation effect of WSD towards the occurrence of SMA. These special patterns of correlations identified among the variables fulfilled the criteria to postulate the mediation effect and necessitated the analysis using regression statistics for conclusive evidence of the mediation effect.

Step by step regression analysis (binomial logistic regression) was performed. In the first step, WP, WSD and WD were considered as the predictors for the independent variable (SMA). It was observed that each risk factor (WP, WSD and WD) in their individual capacity was able to significantly predict SMA. As the strength of association between WSD and SMA was higher in comparison to WP and WD; it is realized that WSD might be the variable which possibly could play the mediating role. Subsequently in the second step, regression analysis was performed keeping a combination of predictors (WP and WSD; WD and WSD). Results of this analysis showed that in the presence of WSD as a predictor, the individual capacity of both WP and WD was reduced greatly and were no longer significant in the prediction of SMA. However, in the presence of either WP or WD, WSD was able to significantly predict SMA exhibiting the mediation effect. In the next step (step-III), regression analysis was performed by keeping all the three variables (WP, WSD and WD) in the predictor list and SMA as the independent variable. The results at this stage showed that WSD significantly predicted the occurrence of SMA, whereas the capability of WP and WD to predict SMA was not significant. Hence, it was evident that, WSD exhibited the mediation effect upon other risk factors considered for predicting the occurrence of SMA (Sanjog et al., 2015 b).

Binomial logistic regression finally aided for proposing a model (Model- IV) where WSD had a significant mediating effect upon both WP and WD; in predicting SMA. It established **(fulfilling the objective - 2 of the research work)** the fact that the occurrence of SMA due to awkward WP and poor WD was exaggerated through WSD. **Hence the hypothesis - H_1 of the research work is established.** Therefore, controlling WSD could be the solution towards reducing the occurrence of the symptoms of musculoskeletal ailments in the Indian small and medium scale injection-molded plastic furniture manufacturing industries; if the scope for correcting poor workstation design, changing working postures and subsequent modification of work methods were limited / constrained by other factors. Exposure to awkward working posture is a common problem in many countries and the majority of work-related musculoskeletal disorders may be mitigated with the help of ergonomic interventions (Fallentin et al., 2001).

The recommendations given by The Factories Act (1948) of the Government of India with respect to working hours for adults are as follows.

- The maximum permissible working hours for adults is forty-eight hours in any week and no adult worker shall be required or allowed to work in a factory for more than nine hours in any day.
- The period of work for adult workers should not be more than five hours before the worker has had an interval for rest for at least half an hour.
- The periods of work (for an adult worker) shall be so arranged that inclusive of intervals for rest shall not spread over more than ten and a half hours in any day provided the chief inspector may for reasons specified in writing may increase the spread over up to twelve hours.
- The worker is entitled to wages at the rate of twice the ordinary rate of wages for working more than nine hours in any day or more than forty-eight hours in any week.

As day-long video recording was not permitted by factory managements, computing the frequencies of individual working postures and their relative proportions (%) of working time was not possible. This limits measuring the amount of time spent in each posture. Since work shift duration in the factories is generally of 8 or 12 hours and activities are recurring in nature, it is reasonable to assume that considerably large amounts of time are spent by workers in each posture.

2.11 Conclusion

The existence of physical risk factors is very common in the Indian small and medium scale manufacturing industries in India (Biswas et al., 2012; Rai et al., 2012; Singh, 2012), as also revealed in this study. Awkward working postures, work shift duration and poor workstation design were identified as the risk factors leading to the prevalence of the symptoms of musculoskeletal ailments. All the individual risk factors and the symptoms thereof were significantly correlated with each other. Mediation statistics revealed that work shift duration significantly mediated the impact of workstation design and work posture in the occurrence of the symptoms of musculoskeletal ailments. Suitable steps should be taken to justify and define the duration of work exposure, since prolonged working hours are attributed to a wide range of health problems as also mentioned by Bannai and Tamakoshi (2014). The proposed final 'mediation model' is perhaps the first of its kind in occupational health research (Sanjog et al., 2015 b). Findings would help in the formulation of ergonomic intervention strategies in existing as well as forthcoming injection-molded plastic furniture manufacturing factories in the small and medium scale industrial sector in India.

Chapter III

Reduction of hand grip strength as an indicator towards discomfort of upper body extremities

Abstract

The aim of the present chapter is to assess the hand grip strength before and after work among the male shop-floor workers in injection molded plastic furniture manufacturing factories. Hand grip strength dynamometer was used in the present study. Observations revealed a significant reduction in the hand grip strength before and after work in both the hands among shop floor workers. The reduction in hand grip strength may indicate the likelihood of shop-floor workers developing upper limb musculoskeletal disorders in due course of time. Reduction in hand grip strength may also be due to muscle fatigue. Hence, investigations towards identification of ergonomics risk factors may be initiated in the small and medium scale injection molded plastic furniture manufacturing industries, followed by implementation of ergonomics design interventions towards realizing human centric production systems.

3.1 Introduction

It has been reported that Work-related Musculoskeletal Disorders (WMSDs) of the upper extremities are common causes of pain in body parts (Alperovitch-Najenson et al., 2004). Identification of risk factors (physical work load, unfavorable body posture, vibration, psychosocial factors and repetitive or monotonous tasks) associated with reduced upper extremity function may lead to the development of more effective interventions (Alperovitch-Najenson et al., 2004). Even when strength demands are quite small, significant levels of fatigue and discomfort are produced when people work with hands and arms above level of heart or at the limits of range of motion (Wiker et al., 1990). Micro Small and Medium Enterprises (MSMEs) are intended to be labor intensive for providing large employment opportunities at lower capital cost. Large numbers of human resources are employed in shop-floor of Indian plastic processing industries as manufacturing processes are not completely automated. Therefore, it is necessary to investigate the need for initiating intervention programs in shop-floor workstations of small and medium scale injection-molded plastic furniture manufacturing factories from an ergonomics perspective.

3.2 Aim

Assess the hand grip strength before and after work among the shop-floor workers in injection-molded plastic furniture manufacturing factories.

3.3 Methodology

3.3.1 Selection of factories, workstations and workers for survey

(Refer Chapter II; section 2.7.1)

3.3.2 Study of body-parts discomfort

Standardized Nordic Questionnaire (SNQ) was used to investigate the occurrence of musculoskeletal troubles and identify suffered body parts (Kuorinka et al., 1987) in upper limbs. The procedure involved showing a body map to workers / volunteers and elucidating responses to selected queries in SNQ.

3.3.3 Selection of hand grip strength measuring instrument

From a survey of various literature it is reported that Jamar hand dynamometer is a reliable instrument (Shechtman, 2000), both for inter-rater reliability and test-retest reliability (Innes, 1999) and is commonly / popularly used for measuring grip strength (McDowell et al., 2012). Therefore in the present case study Jamar hand dynamometer was used to measure hand grip strength.

3.3.4 Measurement of hand grip strength

Hand grip strength data was collected before commencing work, immediately after work from experimental group and control group in present case study. Factories were following six day a week work plan. All employees constituting the control group were found to be working for 8 hours / day. Measurements were taken at the end of 8 hours and also immediately after work at the end of 12 hours for workers who were working for 12 hours / day in the experimental groups. Workers were made to stand in a comfortable position, shoulder adducted and neutrally rotated, elbow flexed to 90 degrees, forearm, and wrist in neutral position as recommended by various researchers (Peolsson et al., 2001; Scott, 2006; Koley et al., 2009; McDowell et al., 2012). Test volunteers may sit or stand in a comfortable position, shoulder adducted and neutrally rotated, elbow flexed to 90 degrees, forearm, wrist in a neutral position with each test repeated three times and average value is to be noted (Lafayette Instrument Co. 2008). From literature (Härkönen et al., 1993; Firrell and Crain, 1996; Innes, 1999; Ruiz-Ruiz et al., 2002; Hsi Liao, 2013; Boadella et al., 2005; Lee et al., 2009; McDowell et al., 2012), it was observed that there were dissimilarities in recommendations put forth by researchers regarding optimal grip span. Since there are various opinions among researchers regarding optimal grip span, each worker was asked to take the test at different grip spans and the grip span corresponding to maximum hand grip strength was noted for both hands in present study. Each trial was repeated three times at the optimal grip span identified and average value was noted for both the hands. Workers were asked to press the handle of dynamometer (set at the optimum grip span identified) as hard as possible for a duration of 3-5 seconds and inter task interval of approximately 2 minutes for each trial (three trials to be taken) was permitted to control the effect of fatigue taking into consideration various recommendations as suggested in literature (Scott, 2006; Wolf et al., 1996; Richards et al., 1996; Ahmed, 2013).

3.3.5 Statistical analysis

Appropriate statistical techniques were employed (as per requirement and nature of data) to analyze and interpret collected data using SPSS v.20.0 (IBM, USA) software.

3.4 Observations

3.4.1 Hand grip strength before and after work and comparisons

The hand grip strength before work, after 8 hours of work and after 12 hours of work were recorded and tabulated as shown in table 3.1. Appropriate comparisons (before work vs. after 8 hours of work, after 8 hours of work vs. after 12 hours of work) using Wilcoxon rank sign test among the various groups of workers is also given in table 3.1.

Table 3.1

Hand grip strength before and after work and comparisons

Workers / Employees		Hand	Hand Grip Strength (kilogram-force) (Mean ± SD)			Comparisons (Wilcoxon Sign Rank Test)	
			Before Work	After 8 hours	After 12 hours	Before Work Vs. After 8 hours	After 8 Hours Vs. After 12 hours
Experimental Group	Blending Workstation	Rt	31.8 ± 5.4 (n = 29)	29.5 ± 5.6 (n = 29)	27.2 ± 5.6 (n = 29)	*	*
		Lt	30.7 ± 5.9 (n = 29)	28.9 ± 5.9 (n = 29)	27.6 ± 6.1 (n = 29)	*	*
	Granulator Workstation	Rt	40.60 ± 7.6 (n = 10)	39.40 ± 7.5 (n = 10)	37.2 ± 7.6 (n = 10)	*	*
		Lt	39.1 ± 8.1 (n = 10)	38.2 ± 8.1 (n = 10)	36.4 ± 7.9 (n = 10)	*	*
	Injection-molding Workstation	Rt	37.6 ± 6.5 (n = 46)	35.1 ± 6.1 (n = 46)	32.9 ± 5.9 (n = 42)	*	*
		Lt	36.4 ± 6.6 (n = 46)	35.2 ± 6.5 (n = 46)	33.7 ± 6.4 (n = 42)	*	*
Control Group	Administrative and Supervisory	Rt	35 ± 2.3 (n = 15)	35 ± 2.3 (n = 15)	-	NS	-
		Lt	35 ± 3.4 (n = 15)	35 ± 3.3 (n = 15)	-	NS	-
Experimental Group (combined)	Blending, Granulator, Injection-molding Workstations	Rt	36 ± 6.9 (n = 85)	33.7 ± 6.9 (n = 85)	31.4 ± 6.9 (n = 81)	*	*
		Lt	34.8 ± 7.2 (n = 85)	33.4 ± 7.3 (n = 85)	31.8 ± 7.2 (n = 81)	*	*

Legends: Rt – Right; Lt – Left; NS - no significant difference ($p > 0.05$); * - significant difference ($p \leq 0.05$);

3.4.2 Comparison of hand grip strength between experimental groups (combined) and control group

Comparisons were performed between the combined experimental groups (comprising of workers in blending, granulator and injection-molding workstations) and control group employees with respect to hand grip strength before work and after 8 hours of work as shown in table 3.2.

Table 3.2

Comparison of hand grip strength between experimental groups (combined) and control group

Hand	Time	Hand Grip Strength (kilogram-force) (Mean ± SD)		Comparisons (Wilcoxon Sign Rank Test) Experimental Group Vs. Control Group
		Experimental Group (combined) (n = 85)	Control Group (n = 15)	
Rt	Before Work	36 ± 6.9	36 ± 2.3	NS
	After 8 hours	33.7 ± 6.9	36 ± 2.3	*
Lt	Before Work	34.8 ± 7.2	35 ± 3.4	NS
	After 8 hours	33.4 ± 7.3	35 ± 3.3	*

Legends: Rt – Right; Lt – Left; NS - no significant difference ($p > 0.05$); * - significant difference ($p \leq 0.05$)

3.4.3 Numbers of participants' with body part discomfort in upper limb during last 12 months

The percentage of workers suffering from body part discomfort in the upper limbs (both shoulder, both elbow and both wrist) during the last 12 months in both experimental groups and control group are shown in table 3.3.

Table 3.3

Numbers of participants (% of total number in corresponding workstations) suffering from body part discomfort in upper limb body parts during last 12 months

Body parts	Workers / Employees			
	Experimental Group			Control Group
	Blending Workstation (n = 29)	Granulator Workstation (n = 10)	Injection-molding Workstation (n = 46)	Administrative and Supervisory (n = 15)
Shoulder (both)	20 (69.0 %)	5 (50 %)	26 (56.5%)	0
Elbow (both)	21 (72.4%)	2 (20 %)	6 (13.0 %)	0
Wrist (both)	17 (58.6 %)	5 (50 %)	15 (32.6 %)	0

3.5 Results and Discussions

Comparison (using Mann Whitney U test) of age, weight, stature and experience among control and experimental groups indicated that there were no significant differences except for variable weight between workers of blending and granulator workstations (table 2.3; chapter II). This indicates that participants in each experimental group as well as the control group were of similar age, stature, weight and work experience.

Hand grip strength data was collected before commencing work, immediately after work from the experimental groups and control group. All control group workers were found to be working for 8 hours / day. Measurements were taken at the completion of 8 hours and also immediately after work at the end of 12 hours for workers (who were working for 12 hours / day) in experimental groups.

Decrease in mean hand grip strength was observed at the end of day / working hours (after 8 hours and 12 hours) among shop-floor workers across all workstations (table 3.1). Significant reduction / decrease ($p \leq 0.05$) exists between the mean hand grip strength values before work and after 8 hours across all workers in shop-floor workstations when analyzed using Wilcoxon Sign-Rank Test (table 3.1). Comparison between shop-floor workers' mean handgrip strength after 8 hours and 12 hours also revealed significant reduction / decrease ($p \leq 0.05$) (table 3.1). No significant reduction / decrease ($p > 0.05$) exist between the mean hand grip strength values before work and after 8 hours work in the control group (table 3.1). This suggests that a reduction in hand grip strength experienced by shop-floor workers was job / work specific.

Significant differences ($p \leq 0.05$) were observed (table 3.2) between experimental groups (combined) and control group with respect to mean hand grip strength after 8 hours of work while no significant difference ($p > 0.05$) were observed for hand grip strength before work. **Thus the objective - 3 of the research work is accomplished.** Similar results with respect to hand grip strength were observed using hand dynamometer in studies across other occupations in India (Metgud et al., 2008; Das et al., 2012; Gangopadhyay et al., 2007). People develop upper body discomfort if hand grip strength significantly decreases between before and after work (Das et al., 2012; Gangopadhyay et al., 2007). Numbers of participants (% of the total number in corresponding workstations) suffering from body part discomfort in upper limb body parts during the last 12 months is shown in table 3.3. Based on above results, it is inferred that the study population may be prone to development of upper limb body part musculoskeletal disorder in due course of time.

Muscle fatigue among various other factors like muscle strength, hand dominance, time of day, age, nutritional status, rotator cuff weakness and overall physical function influence the hand grip strength (Scott, 2006; Shea, 2007). Various studies have correlated fatigue with lower strength scores in handgrip dynamometric testing (Shea, 2007). In a study to determine the effect of upper extremity fatigue on grip strength and the passing accuracy in junior basketball players it was reported that the differences between the mean values of pre and post measurements (at $p \leq 0.05$) was due to the effect of upper extremity fatigue on hand grip strength and passing accuracy in basketball (Ahmed, 2013).

Work in small and medium scale injection-molding plastic furniture manufacturing shop-floor workstations involve product / material handling characterized by gripping / holding activities. Activities involving hand gripping may result in fatigue effect on concerned muscles which can be measured through electromyography (EMG) to determine the fatigue spot accurately and also with help of hand grip dynamometer (Susanti et al., 2012). Working postures have been linked / associated for the incidence of muscle fatigue in various studies (Straker et al., 1997; Areeudomwong et al., 2012; Balasubramanian, 2011). Awkward arm postures, working with arms above shoulder height, working with hands, arms above heart level and at the limits of range of motion lead to muscle fatigue (Wiker et al., 1990; Fuller et al., 2011). Due to physiological reasons and mechanics, strength is dependent and greatly influenced by the working posture which is subsequently determined by the workplace layout (Pheasant and Haslegrave, 2006). Awkward working postures influenced by work methods and workstation designs were observed in shop-floor workstations.

Design of working environments from a postural perspective should develop principles for incidence of low postural stress on workers which will help in reducing the incidence of fatigue and discomfort (Bridger, 2002). Proper workstation design facilitating good operating postures, less material handling, reduction in task completion times may help in minimizing muscle fatigue levels to a great extent as indicated by studies in other occupations (Chaffin, 1973; Metgud et al., 2008). Identification of risk factors will lead to the development of more effective interventions (Alperovitch-Najenson et al., 2004). Scope towards conceiving of design interventions from an ergonomics perspective is very significant in MSMEs, as restrictions on investment in plant and machinery (for achieving complete automation) is enforced in order to avail incentives from government agencies. Research towards comprehending and implementation of ergonomic design interventions will immensely benefit the huge work force expected to be employed in the Indian plastic processing industries in addition to presently employed workers.

3.6 Conclusion

Findings of present study may serve as an endorsement for initiating detailed investigations towards identification of physical risk factors and thereafter implementation of appropriate design interventions (from an ergonomics perspective) for developing human centric production systems in the Indian small and medium scale injection-molded plastic furniture manufacturing industries.

Chapter IV

Context specific ergonomic design interventions in blending, granulator and injection-molding workstations

Abstract

Investigations pertaining to workstation designs, working postures and work methods / activities from an ergonomics perspective are less reported from manufacturing shop floors of Industrially Developing Countries (IDCs) like India. Prevalence of manual labor and locally designed workplace fixtures are usually observed in shop-floor workstations. Aim of the present chapter is to identify the incidence of awkward working postures among workers in the shop floor of injection-molded plastic furniture manufacturing industries and propose design modifications from an ergonomics perspective. A combination of research techniques comprising of questionnaire study, postural assessment tools, statistical analysis, digital human modeling and work study was used to accomplish the stated aim. Workstation accessories designs were not in accordance with the recommended guidelines. Workstation design and work methods were found incompatible with worker's anthropometry and thus led to the prevalence of awkward working postures. Investigations pertaining to psychosocial work environment and subjective workload assessments helped in understanding the type of design interventions required in each workstation. Ergonomic interventions in terms of redesigning of workstation and work accessories were evaluated in virtual environment of the CAD software. Redesign of workstation accessories (considering demographic constraints and recommended guidelines) and subsequent modification of work methods, enabled improvement of working postures. Work study techniques helped to understand the effectiveness of the proposed design interventions with respect to the work elements in a work cycle.

4.1 Introduction

The workers' occupational health should be given paramount importance in any work environment. Improvement in work satisfaction, productivity and workers well-being can be achieved only if workstations and work environments are designed in accordance with the recommended guidelines put forth by scientific organizations and also conforming to the laws of work. Investigations and applications are mostly observed to be reactive in scenarios where less attention is given towards man-machine compatibility while installing and commissioning work systems. Mass production brings about consistency in manufacturing industries thus making the job to be completed by the workers (characterized by varied anthropometry and capabilities) performing standard tasks. Typically, manufacturing tasks repeated thousands of times a day in standardized workplaces are forcing the workers to adapt, resulting in the incidence of musculoskeletal disorders / cumulative trauma disorders / repetitive motion syndromes among the workers (Ostrom, 1993). The human factor is a cause of deep concern as human operators are viewed as the adaptive element in modern manufacturing systems and as a result simulation of human tasks is very important in manufacturing systems design, assessment and improvement (Zhang et al., 2008).

Reliance on physical mockups of products and trials using real humans as subjects / volunteers in traditional investigation techniques are time consuming and costly (Helander, 1999). Computer aided digital human modeling and simulation technology has emerged as the state-of-the- art technology (Karmakar et al. 2012). Longo and Monteil (2011) has identified ergonomics, work measurement and their combination with digital human modeling and simulation as three main scientific approaches for industrial workplace design with the latter approach always providing researchers and practitioners with challenging opportunities and also helping to find solutions. The above mentioned conclusions by Longo and Monteil (2011) was proposed after reviewing case studies (from countries like USA, Isreal, China, Spain, Sweden and Italy) whose objectives was designing of industrial workstations including layout rearrangements comparable to the results achieved in present research work.

The manufacturing strategies adopted by the majority of the Indian companies have similarity with third world countries and does not conform to world class practices (Dangayach and Deshmukh, 2000). Complex man-machine relationship and its associated environment are highly potential areas of research in the Indian industry (Gosh, 2005). Industrially Developing Countries (IDCs) are characterized by the heterogeneous array of cultures, people surviving in habitats of limited natural resources, poverty, under production and human labor power based functioning systems (Mrunalini, 2007). Therefore, the application of ergonomics in IDCs should be related to the demographic region under consideration (Mrunalini, 2007). Very few attempts had been made to apply ergonomic principles in an organized manner in Indian industries and lack of communication with other functional areas (production, design, safety and industrial engineering) are the major reasons for the current negligible application of ergonomics in industrial practice (Ganguly, 2013).

Investigation (from an ergonomics perspective) in manufacturing sectors is of utmost necessity to address the challenges in workstation designs and work methods in present-day Indian and IDC scenario.

The Indian plastic processing industries are highly fragmented, comprising of micro small and medium enterprises (Central Institute of Plastics Engineering and Technology, 2010). Less automation, the prevalence of manual labor, locally designed implements and work place fixtures are usually observed in the machine shop-floor. Workstation and work method investigations from the design ergonomics perspective are less reported from the manufacturing shop-floors of industrially developing countries (IDCs) like India.

From review of literature it has been observed that investigations from ergonomics perspectives have not been performed in the Indian small and medium scale plastic processing sector. Foreseeing the tremendous growth of plastic processing activities in India; an investigation focused on identifying physical, psychosocial and subjective workload risk factors was performed in the shop-floor workstations of existing injection-molded plastic furniture manufacturing industries (an important constituent of plastic processing industries) in order to propose context specific design interventions from ergonomics perspectives. An innovative combination of techniques featuring direct observation, questionnaire study, postural assessment, digital human modeling and simulation, work study and statistical analysis were utilized for achieving the stated aim of the present study. Researchers, production managers / supervisors / engineers in manufacturing MSMEs of industrially developing countries like India may adopt the research methodology presented for proposing and implementing appropriate context specific design interventions for humanizing work activities in the shop-floor workstations.

4.2 Workplace design in the manufacturing sector: An ergonomic perspective

The anthropometric considerations of the intended end user are given scant attention and as a result manufacturing workstations are arbitrary designed (Das, 1998). Conventional approaches to workplace design mostly overlook the problems related to anthropometric and biomechanical aspects (which are an indispensible part in workplace designs) while performing a task (Jensen, 2002). Ergonomics finds a low level of acceptance and the limited number of applications thus resulting in poorly designed work systems in the manufacturing industries (Shikdar et al., 2002). Thus the loss of productivity, employee turnover, less employee satisfaction in work and occupation related health disorders and errors / accidents are bound to happen as a result of traditional workplace design practices. As evaluations using human beings are not done at the early design stage of workplaces, severe consequences happen on physiological, mental and psychological wellbeing of individuals using it (Udosen, 2006). Unsatisfactory production ergonomics is the leading cause of sick leave and work injuries in the manufacturing industry (Lämkull et al., 2009 a). It is also observed that since technical and cost considerations play a major role in production designs, attention to ergonomic considerations come after addressing other design factors / problems (Helin et al., 2007). Ergonomics should be simultaneously considered in the design process to guarantee good usability and overall performance while avoiding extra costs of redesign and corrective actions in typical manufacturing workstation activities (Helin et al., 2007). Application of ergonomic principles will help in increasing comfort and productivity if active participation from users and management are forthcoming (Vink et al., 2009). Ergonomics should be applied with active collaboration between academia and industry (Sanjog et al., 2012 a).

4.3 Postures

4.3.1 Factors influencing postures in workplace

Worker, workstation and operation characteristics determine the working posture (Delleman, 2004). Mostly the working posture adopted for a task is directly determined by the dimensions and the arrangement of workplace and equipment used particularly in relation to other factors like work height, reach distance, the field of view and space to move freely (Delleman et al., 2004). Workplace working posture is determined by interaction of many factors, including workstation layout (heights of conveyors, reach distances to access pallets and storage bins), equipment design (position of machine controls, location of visual displays) and work methods (sequence of work tasks, tool selection and work technique) (Keyserling, 1998). The workstation layout, visual demands of the job, design of equipment and tools, anthropometric characteristics of worker and work methods govern the workers' body position / postures when executing a task (Keyserling et al., 1993). Quite often undesirable posture may not be due to bad working habits of the person but primarily due to poor design of equipment and furniture (MacLeod, 2000).

4.3.2 Awkward working postures and consequences

The awkward postures identified include standing, sitting without support for the back, sitting without foot rests of correct height, sitting with elbows rested on a high working surface, the upper arm hanging unsupported, arms reaching upward, head bent back, the trunk bent backwards, lifting heavy weights with back bent forwards, maintenance of any joint in its extreme position, raised elbows, reaching behind the torso, extreme elbow flexion, outward and inward forearm rotation, wrist flexion and extreme wrist extension, radial and ulnar deviation, power and pinch grip (Genaidy et al., 1994).

Poor workstation design and lack of compatibility with anthropometric needs of the employees result in poor posture as well as pain and discomfort (Shuval and Donchin, 2005). Postures are created by work methods and it is widely considered that more the deviation of a joint from the neutral (natural) position, greater is the risk of injury (Singh, 2007). Work-related Musculoskeletal Disorders (WMSDs) affect workers in a wide variety of occupations and may typically take months or even years to develop leading to lost time from work, workers' disability, compensation claims and health care costs (Franco and Fusetti, 2004). Awkward postures if assumed repetitively or for prolonged periods are bound to result in increased rates of fatigue, discomfort and incidence of injury (Punnett et al., 1991). Pains or symptoms of musculoskeletal disorders are definitely due to poor postures (Genaidy et al., 1994). Back pain mostly resulted from improper (mild / severe flexion, twisted and bent) trunk posture while undesirable neck postures (mild / severe flexion, twist, bent and extension) caused pain in neck, upper back, shoulder, arms, and headache (Keyserling et al., 1992). In a study of automobile assembly workers; it was revealed that non-neutral postures such as working forward, bending more than 20 degree from the vertical and twisting more than 20 degree from forward facing position were significant contributing factors to work related back pain (Punnett et al., 1991). Flexed postures over 60 degree adopted for more than 5 % of work time increased the risk for developing musculoskeletal troubles by 50 % while twisted postures adopted for more than 10 % of the work time augmented the risk by 30 % (Dieën and Nussbaum, 2004). Postural discomfort occurs when joints are in extreme position of rotation while postural comfort is greatest in resting position or when joints are in the midpoint of their range of movement (Corlett and Clark, 1995). Mechanical load on lumbar spine is a contributing factor to disorders of back including low-back pain (Chaffin and Andersson, 1991). Non-value added time in production activities may slow down basic work motions as a result of awkward postures (Shoaf and Genaidy, 1998). Removal or reduction of awkward work posture is one of the important objectives for workplace ergonomic intervention programs as awkward working posture results in fatigue, discomfort and disability (Keyserling et al., 1993).

4.3.3 Recommendations for achieving good working postures

Jobs should be designed for working in a neutral posture to the maximum extent possible (Punnett et al., 1991). Concerning the range of body segment movements, a neutral range is the maximum range of motion which results in minimal discomfort to joints and adjacent body segments (Delleman, 2004). Design of the workplace should allow tasks to be performed with arms close to the body and below shoulder level as biomechanical forces increase when the reach distance is increased (Gandjean, 1990). For example, trunk and neck should be nearly vertical with minimal twisting or bending (forward, backward or sideways) while both the arms should be comfortably down from shoulders approximately parallel to the trunk in case of a standing worker. Minimizing trunk deviations from the neutral posture can help in reducing discomfort and non-neutral trunk postures cause more mechanical load, more muscle fatigue, more discomfort and more health risk (Dieën and Nussbaum, 2004). Good standing posture (minimum biomechanical stresses) is the one in which person’s back is straight and head is in line with shoulder and hip joint while knees should be bent at ninety degree angle for a good sitting posture (Ostrom, 1993). Muscles are said to be in their optimal strength when in neutral position and this advantage may be utilized while designing for neutral posture (MacLeod, 2000).

Task redesign should be achieved by avoiding twisting or rotating movements, using gravity to move load when possible using mechanical aids (handles, trolleys, hoists or slides), reducing load weight to the lowest possible level and handling load close to the body (between knuckle and shoulder joint) (Shoaf and Genaidy, 1998).

While designing or evaluation of any work activity, it should be kept in mind that the upper limit for regular manipulation of tasks is about chest height (Kroemer, 2003).

Twisting of body positions, forward bending (of trunk, neck and head), postures that need to be maintained for longer periods of time and holding arms in raised position are some of the basic design faults to be avoided in a workplace (Kroemer, 2003).

Work is normally done properly at elbow height whether sitting or standing (Macleod, 2000). Adjustable features should necessarily be included in the workplace for simultaneously accommodating the desired population and achieving the desired posture (Delleman et al., 2004). Postural stress on standing workers due to stooping or working with hands and arms elevated may be minimized by placing all objects necessary for work between hip and shoulder height (Bridger, 2002). Depending on the task, the work surface height should be approximately close to standing elbow height of workers (Bridger, 2002). General guidelines for work posture include encouraging frequent changes of work posture, avoidance of forward inclination of the head and trunk, prevention of raised position of the upper limbs, evasion of twisted and asymmetrical postures (Pheasant and Haslegrave, 2006).

Manual material handling (lifting, carrying, pushing and pulling) forms a major occupational risk factor which must necessarily be kept within safe and recommended limits (Capodaglio et al., 1997). Pains or symptoms of musculoskeletal disorders are associated with poor body postures and redesigning of Manual material handling tasks included postural analysis, biomechanical analysis, physiological and subjective measurements of specific tasks (Ciriello et al., 1999). It is recommended that constant effort should be endeavored for redesigning MMH tasks which are not according to good ergonomic principles (Ciriello et al., 1999). Redesign approaches for material handling activities generally involved minimizing hand distances, decreasing quantity of loads (lifting, lowering, and carrying), decreasing frequencies of tasks, increasing heights of start for lifts and decreasing the distances (of carries, pushes and pulls) (Ciriello et al., 1999).

A worker survey must be conducted to determine the influence of equipment or system design on employee comfort, health, ease of use of equipment before redesigning an existing workstation as the survey response will be definitely useful in recommending changes to existing workstation design on ergonomics principles (Das, 1998). Anthropometrics should be to be compared with the product and workplace

measurements in an ideal design process since fit between products, workplaces and users are not always optimal thereby leading to musculoskeletal disorders (Hanson et al., 2009). Details of task performance, equipment, working posture and environment are important while designing a workstation for manufacturing (Das, 1998). It was observed that the majority of the successful intervention projects involved modifications to the workstation layout in order to facilitate reduction / elimination of low and far or overhead reaches related with awkward trunk and shoulder postures, whereas changes / interventions in product design and manufacturing process changes were generally not observed (Keyserling et al., 1993). It is very important for designer to test various work area arrangements in order to obtain satisfactory solutions from ergonomics perspective (Swat and Krzychowicz, 1996).

Tremendous scope exists in improving workspace design as awkward trunk postures are reported to be one of the major causes of low back pain which is highly prevalent in the industrialized world (Dieën and Nussbaum, 2004). Numerous jobs requiring physical work are observed in the industrialized and developing countries in spite of rapid technological developments (Louhevaara, 2003). Manual material handling activities involving heavy physical work (requiring continuous or repetitive movements) will remain indispensible in spite of rapid technological developments in many jobs (Louhevaara, 2003). Work related disorders are still very prevalent even though efforts have been made to improve working conditions (Balogh et al., 2006). Workstation and its components should exhibit accurate dimensions and be easily adjustable in order to meet anthropometric characteristics and requirements of a wide range of users (Grieco et al., 2004). Minute changes in workstation dimensions are found to have a tremendous effect on productivity, occupational health and safety of the workers (Das, 1998). Alteration of heights and reaches, tilting of equipment, redesigning / modifying equipment layouts and designing pistol grip or modular grip tools will help in improving posture (Macleod, 2000). The reduction in workers hand and arm motions may be achieved by altering heights, reaches, location and orientation of materials and overall movements may be reduced through efficient workstation layout (Macleod, 2000).

4.4 Psychosocial work environment: importance in occupational ergonomics

The psychosocial work environment should be considered for research in the practice of occupational ergonomics since it is crucial for ergonomic interventions and importantly physical and psychosocial work environment relate to work related musculoskeletal disorders (Carayon and Lim, 2003). It is reported from various literature (Ariens et al., 2001; Hanse, 2002; Hannan et al., 2005; Hägg and Åström, 1997; Sjøgaard et al., 2000) that psychosocial factors are related to work related musculoskeletal disorders and that physical and psychosocial factors are often associated with each other (Arvidsson, 2008). Work pace and psychosocial working conditions play an important role in the prevalence of musculoskeletal disorders among workers (Bongers et al., 1993). The most often used method for measuring psychosocial work factors in applied settings is the questionnaire survey (Carayon and Lim, 2003).

4.4.1 Investigation of psychosocial work environment in Indian Scenario

The psychosocial work environment has been considered in research pertaining to anxiety and depression among HIV -infected heterosexuals (Chandra et al., 1998), genital complaints in women (Patel et al., 2006), risk factors for suicides (Gururaj et al., 2004; Manoranjitham et al., 2010), musculoskeletal disorders / symptoms in information technology industry (Mehta and Parijat, 2012; Sharan et al., 2011), hazards and health complaints in activities related to fish processing (Nag and Nag, 2007), medical problems in geriatric population (Gupta et al., 2012), construction workers (Tiwary et al., 2013), parents of children with loco motor disability (Laskar et al., 2010), work environment in garment industries (Padmini and Venmathi, 2012) and women molders in the manual brick manufacturing industry (Bijetri and Sen, 2014) in India. Psychosocial work environment in the small and medium scale injection-molded plastic furniture manufacturing industries have not been investigated till date.

4.5 Subjective workload

Determination of workloads imposed on a human operator plays an important role in designing and evaluating an existing man-machine system (Jung and Jung, 2001).

An important component in the system design and analysis is the evaluation of workload (DiDomenico and Nussbaum, 2008). Designing jobs aimed for low mental workloads in the analysis of task demands is a major goal of work psychology (Rubio et al., 2004). The workload (physical or mental) in an industrial environment may have an impact on the operator's health and performance or productivity (Jung and Jung, 2001). Assessment of mental workload is an essential aspect for the design and evaluation of an occupational task (DiDomenico and Nussbaum, 2011). Investigations relating to mental workload are very important in the development of human-machine interfaces and for ensuring comfort, satisfaction, efficiency and safety in the workplace (Rubio et al., 2004). Industry always aims to reduce the physical and the mental workload (Vink et al., 1995).

Workload is determined by various factors like physical activity, environmental factors and postural discomfort (Karwowski et al., 1986). Studies have proved the existence of positive relationship between physical workload and subjective workload, i.e., as the physical workload increased, workload as perceived by the participant was also expected to increase (Perry et al., 2008). Subjective measurement of workload is based on the use of rankings or scales to measure the amount of workload a person is feeling and are dedicated primarily to the intermittent question-answer type response to varying levels of workload (Miller, 2001). Investigations based on the operator's performance have become extremely difficult and therefore the assessment of the subjective mental workload has become critical in human-machine systems (Rubio et al., 2004). An individual's subjective report of perceptions associated with physical or mental work generally reflects the nature of the task and its demands on physical and mental resources (Annett, 2002). No significant difference was observed between physiological and subjective results, and therefore subjective parameters are as good as the physiological ones to evaluate workload (Guimarães et al., 2012). Research has proved that subjective measures of cognitive workload may be reliable for investigating the actual demands on the operators (Perry et al., 2008). Task designing and redesigning, training policies and selection process may be decided using mental workload analysis (Rubio et al., 2004). Work load ratings can be used to compare differences in workload definition between participants, differences in the sources of workload between tasks, differences in workload during and after work shifts (Dorrian et al., 2011).

4.5.1 Subjective workload assessments in Indian Scenario

The subjective workload assessments have been performed to ascertain the effects of task demand, workload on vigilance performance and stress (Tiwari et al., 2009), effect of training on workload in flight simulation (Singh et al., 2005), mental workload investigations on young Indian adults for selection of optimum font type and size during onscreen reading task performance (Banerjee et al., 2011), the effect of success and failure performance on perceived mental workload (Singh et al., 2010 a), the effects of automation reliability and training on perceived mental workload (Singh et al., 2009 c), monitoring mental workload in an automated system (Singh et al., 2007) in India. Subjective workload assessments in the small and medium scale injection-molded plastic furniture manufacturing industries have not been investigated till date.

4.6 Digital Human Modeling and Simulation

Digital Human Modeling and Simulation (DHMS) refers to the digital representation of human(s) inserted into a simulation or virtual environment in order to facilitate the prediction of safety and / or performance (Demriel and Duffy, 2007 a). Further, digital human modeling may also refer to the procedure of building, creating or designing virtual human models (also known as 'digital manikin') to represent the complex physical and cognitive aspects of human beings. Digital Human Modeling (DHM) is the state-of-art technology for virtual evaluation of products and workstations.

The traditional practice of ergonomic evaluation using physical mock-ups has proved to be time consuming, expensive and risky (Helander, 1999). Evaluations using Digital Mock-Up and Digital Human Models (computer generated two dimensional or three dimensional structure of a human representing the complex physical and cognitive aspects of human beings) are economical in the long run when compared with the traditional evaluation processes in the typical product / process development sequences (Chaffin, 2005; Demriel and Duffy 2007 a). The use of

DHMs have reduced the need for physical mockup tests as DHM does evaluations in a virtual environment (Hanson et al., 2006). Repeated trials which were otherwise not easily possible in traditional investigations are now achievable due to virtual simulations using DHMs. Repeated trials and 3D visualizations are helping engineers / designers to go for design / layout modifications of their product / workplace long before actual prototype development. Many typical concerns of industries such as limited design concept–to–market durations, reduction in prototype building and testing costs, evaluation of what-if scenarios with quick feedback about impending problems and to create more human centered approach in creating products / services are now being addressed with advances in DHMs (Chaffin, 2009). From various literature it has been reported that the requirement of dummy model, cardboard manikin, 2D drawings and real human trials with expensive physical mockups is reduced / eliminated using digital human modeling (Karmakar et al., 2012). Presently it is possible to validate the design concept for a prescribed population even before developing the hardware prototype as shown in the case of International Space Laboratory (Chaffin, 2001). DHM is an inevitable tool for situations involving inaccessible and hazardous environments where trial with living human is both risky and unethical (Chaffin, 2001; Ambrose, 2009). DHM is used as a prospective tool for reducing work related injuries and illnesses (Jimmerson, 2001). It is a great advantage that virtual human modeling technology helps designers to perform analysis / investigations on a realistic 1:1 scale in a virtual environment (Deisinger et al., 2000). Anthropometric dimensions either directly or through the use of digital human models can offer valuable guidance regarding the range of variability needed to accommodate the intended user population (Delleman et al., 2004).

4.6.1 Digital Human Modeling in secondary manufacturing sector

Human variation is the cause for a large percentage of variations between simulation predictions and real world performance in automobile industries (Baines et al., 2004). Ergonomic evaluations using virtual tool may be done in the production phase of car manufacturing (Dukic et al., 2007). Many investigations are being carried out in automobile industries to improve the acceptable limb location of passengers and driver and for improving the vehicle design in accordance with sound ergonomic principles (Meulen and Seidl, 2007). Various task related issues contributing to ergonomic problems were identified during a case study of a simulated assembly operation in an automobile plant (Lämkull et al. 2009 a). DHMS is being successfully used in cycle time reduction in order to improve the transition from engineering design to production in industries which deals with engine and related technologies, including its design and manufacturing (Demirel et al., 2006). A user centered vehicle layout concept was systematically generated from an ergonomic point of view using DHM software giving due consideration to trunk loading and unloading movements (Mueller and Maier, 2011).

Major aircraft manufacturers are also using DHM tools for studying the assembly process in their manufacturing facility (Curran et al., 2007). Positioning of digital human models in airplane passenger seats reveals the extent to which DHM is helpful in understanding and evaluating the design from user point of view (Green et al., 2010).

Longo and Monteil (2011) reported that DHMs have been used in ergonomic design of workstation in an industry which was manufacturing high pressure hoses. Similar software has also been applied in production design for ensuring better quality of end product and manufacturing equipment (Bubb and Fritzsche, 2009). Taking sewing machine operation as an example of a task involving complex and precise visual demands, Doi and Haslegrave (2003) evaluated postural behavior of an operator using Jack DHM software. Computer aided ergonomics has found very little mention in the highly advanced computer integrated manufacturing techniques / strategies adopted in today's manufacturing sector (Sanjog et al., 2012 b) as styling and engineering design elements are given much importance (Summerskill and Marshall, 2011).

Modifications and alterations in the workplace once designed and implemented are very difficult as it incurs more time and a huge expenditure of money. Hence designers / engineers should adopt proactive ergonomic design approach instead of reactive one. Application of Digital Human Modeling and simulation software thus will be a necessary tool for implementing proactive ergonomics (Chaffin, 2005). From a survey result, it was clearly observed that over 90% of the system designers and engineers recognized that they need to consider ergonomics earlier in their design development process (Broberg, 1997). Human capabilities and limitations should be considered in addition to technical specifications while designing manufacturing systems (Shahrokhi and Bernard, 2009).

4.6.2 Application of DHM in the manufacturing sector of industrially developing countries

The majority of small and medium scale industries are still unaware of DHM simulation tools (Santos et al., 2007). Application of DHM for virtual evaluation of manufacturing workstations and associated tasks is less reported in industrially developing countries (Sanjog et al., 2012 c). Reasons for lack of widespread application of DHM technology in developing countries can be attributed to difficulty in incorporating customized data base in software due to lack of appropriate national anthropometric data bases for most of the developing countries, except a few like China and South Korea (Luximon et al., 2012; Baek and Lee, 2012). Moreover, huge ethnographic variations due to mixing of various races make it difficult to develop national anthropometric and biomechanical data base for countries like India. DHM tools require substantial monetary investments and training which can be afforded mostly by large and resourceful companies (Laring et al., 2005) in developed countries. Lack of awareness is another factor contributing to the negligible application of this technology among fast developing economies like India, Pakistan, Bangladesh, Russia, Syria, Thailand and other similar countries. The low rate of progression in Information Technology (IT) and less adoption of advanced computing techniques might be important factors behind less use of CAD and DHM in many developing countries.

4.6.3 Need for DHM inclusive approach in evaluation of manufacturing workstations

Traditional investigations involving physical mockups of the product, workspace and real workers being used in different combinations is both time consuming and costly (Karmakar et al., 2011) thereby does not confirm to goals of modern industry rendering it practically not feasible (Mavrikios et al., 2007 a). Further, once any workstation is developed and commissioned there exist only a remote chance of making additional design changes without incurring huge additional expenditure and time (Karmakar et al., 2012). The goal of manufacturing industry to achieve human integrated design of products and process (Mavrikios et al., 2007 b) can be achieved only if the abilities of the operators are matched with task requirements as well as with the working environment with due consideration to physical constraints (Longo, and Monteil, 2011). In this context DHM software provides an excellent opportunity for accomplishing ergonomic assessments as it is interfaced with the 3D computer aided designs thereby reducing a number of assumptions on which traditional ergonomic evaluations are grounded upon (Stephens and Jones, 2009). Interactions between workers and their working environment always provide challenging problems due to high complexity of the manufacturing systems (Cimino et al., 2009). DHM, along with computer aided workplace designs can help in completing the entire ergonomic evaluations using numerous virtual setups of workspace incurring less time and cost when compared with the traditional analysis (Mavrikios et al., 2007b; Jayaram et al., 2006). DHMs capability to interact with digital workstations and subsequently virtual evaluations of workstation layout, workflow simulation, assembly accessibility, reach, clearance, strength capability studies, safety analysis, assembly feasibility, process compatibility issues, posture and movement simulations (arms, legs, torso) using inverse kinematics, vision simulation, joint dependent comfort / discomfort evaluations, maximum force calculations and the center of gravity analysis together with the generation of a large amount of biomechanical information (spinal compression and shear forces) based on thousands of postures from an entire task simulation is more than an ergonomist has had before (Bubb and Fritzsche, 2009; Stephens and Jones, 2009). DHM facilitates a complete data based ergonomic analysis and provides a strong scientific validity to solutions proposed or implemented. Biomechanical assessment like overexertion of lumbar spine (from assessing lumbar load) for investigating the occupational health activities even with the additional help of gender-related limits based on load-bearing capacity of spinal elements is very useful for predicting occupational health risks (Jäger et al., 2001). Therefore, the validity of design interventions (visualized by safe and comfortable working postures of digital human models) is satisfactorily assured. Simulation using DHM software appears to be a necessary condition for evaluating and modifying existing manufacturing workstations without disturbing the existing manufacturing activities in the production line.

Man-machine interaction which happens in the workstation is an indispensible part in the manufacturing environment wherein lies a tremendous scope for improvements through proper design from ergonomics viewpoint. Widespread prevalence of MSDs in today's manufacturing scenario justifies the need to design production systems that fit workers' structural and functional anthropometry. Reduced frequency and severity of accidents, improved job performance, fewer days lost to injuries, improved user acceptance, improved efficiency, improved effectiveness, reduced design and manufacturing costs, increased standardization, shorter training time, protection from litigation, greater job satisfaction, less employee turnover and less user fatigue are some of the immense benefits of proactive ergonomics (Gabriel, 2003); which manufacturing industries in industrially developing countries can / should utilize with the help of DHM as a lack of published literature in the framework of manufacturing workstations / shop-floor in industrially developing countries is observed. Ergonomic evaluations by exploring what if scenarios with quick information by providing details about population capabilities and specific outputs with reference to specific design attributes of interest greatly benefit engineers and designers (Chaffin, 2009) in the design of human centered manufacturing workstations.

Simulation using DHM software appears to be a necessary condition for evaluating and modifying existing manufacturing workstations without disturbing existing manufacturing activities in the production line. Chaffin, (2001) had stated that DHM is moving into mainstream design for workplaces while Hanson et al. (2006) has inferred from other DHM users that human modeling tools will bring about the development of a standard ergonomic evaluation methodology thus ultimately becoming a standard validation and benchmarking method.

The necessity of developing and implementing human centered workplace with the help of computer aided ergonomics incorporating DHM as one of the important manufacturing strategies to improve productivity and other relevant parameters is needed in the manufacturing industries of industrially developing countries in order to survive and remain globally competitive. While suggesting above recommendation, it is comprehended that there is need to educate manufacturing industries including small scale enterprises to make them understand long term benefits realizable in product and workstation design using DHM technology.

4.6.4 DHM based Ergonomic assessment of manufacturing workstation– examples

Manufacturing industries in industrially developed countries has benefitted when DHM was used for manufacturing workstation / workplace evaluations as can be envisaged from the following paragraphs. DHM addresses some of the engineering concerns also.

The posture based ergonomic analysis was used to arrive at the inferences relating to ergonomic efficiency of the process (identification of critical points based on comfort scores resulting in redesign of actions to reduce the worker's fatigue and the task's execution time to optimize the task from an ergonomic viewpoint) in the design of the assembly workplace for a commercial refrigerator manufacturing industry (Mavrikios et al., 2007 b). DHM with reasonable accuracy addresses reachability concerns in production work places and is also useful to design the dimensions of production assembly, the geometric design of equipment according to anthropometric demands (Bubb, 2007). DHM can also be used to analyze existing human motions, lifting behaviors with respect to current / mock-up workstations, and then modified for different scenarios for different standing heights, alternative workstation geometries; while taking into account lower back compression forces, joint strength requirements, effects of standing height on biomechanical stresses and propose modified workstation designs thereby improving design layouts (Rider et al., 2003). A methodology was proposed for ergonomic design of industrial workstations (high pressure hydraulic hose manufacturing) based on multiple design parameters (objects dimensions, tools position and operator work methods) affecting performance measures related to work measurement and ergonomics, supported by a simulation model that recreates workstations in a 3-D virtual environment along with inclusion of digital human models (Cimino et al., 2009). Another case study in a workspace involving a worker, milling machine and its associated tasks (bringing and registering the board, charging NC part program, cleaning and placing the board in the pallet) were simulated and investigated using DHM and it was found that such an ergonomic analysis made a possible reduction of idle time and simulation for a wide range of workplace scenarios (Santos et al., 2007). A review the regarding industrial workstation design based on DHM and simulation by Longo and Monteil (2011) revealed that majority had ergonomic objectives in mind followed by safety and operational goals and the studies mostly resulted in layout rearrangement while some studies resulted in elimination of hazardous movements and organizational changes.

The automobile manufacturing sector has also seen instances where DHM was applied to practical use successfully. Peacock et al. (2001) of Manufacturing Ergonomics Laboratory (General Motors Corporation) observes that sheet metal handling is a complex process where production rates in certain sections are governed by the process, need to maintain sufficient inventory levels for meeting production requirements and high capital costs of equipment necessitates continuous production at full capacity with least downtime. They have opined that in such a demanding scenario spatial characteristics of workplaces (heights, orientation, reaches and accessibility) and qualitative, quantitative questions regarding physical parameters of task (weights, shapes, clearances, distances, locations, orientation, pathways, movements, moments, targets and interfaces) need to be optimized for a collision free environment between parts, equipment and people which require sophisticated ergonomic analysis. In this context, DHM was successfully used to examine a sheet metal handling process and important policy decisions were taken. The participatory approach with the inclusion of DHM in ergonomic analysis has resulted in design changes facilitating decreased assembly times; decreased work related physical stress and reduced rework thus improving assembly work in an automotive industry (Sundin et al., 2004). Worker safety issues were studied while installing a new satellite digital antenna radio system at Ford Motor Co. and it was observed that DHM facilitates cost savings in real terms by integration of design, management, marketing, manufacturing and training departments within a company when integrated with product lifecycle management software (Demirel and Duffy, 2007 b). Lämkull et al. (2009 b) reported that relationship between principles of ergonomics with manufacturing quality, time to market, musculoskeletal disorders and their combined implications on productivity are the major reasons for use of DHM tools in automotive manufacturing industries. They also highlighted that DHM tools with the advantage of having statistical description of population attributes (size and range of motion) are applied in design, modification, visualization, and analysis of workplace layouts. DHMs are also widely utilized to predict postures and ergonomic stresses accompanying automotive assembly tasks including manual assembly tasks for providing designs for standing and unconstrained working postures (Lämkull et al., 2009 a).

DHM addresses issues / concerns like workstation layout, workflow simulation, assembly accessibility, reach, clearance, strength capability, safety analysis, assembly feasibility, process compatibility, posture and movement simulations, vision simulation, joint dependent comfort / discomfort evaluations, maximum force calculations, center of gravity analysis, biomechanical analysis and unintentional / hazardous human-machine contact / interaction. The application of DHM has resulted in redesign of actions to reduce the worker's fatigue and the task's execution time, propose modification in workstation designs, improve layout designs, design dimensions for production assembly and equipment. Investigations using DHM has also helped to reduce assembly times, physical work (in shop-floor of manufacturing industries) which ergonomists, engineers and designers aim at.

4.6.5 Digital Human Modeling and Simulation: Indian Scenario

Developed countries are widely using DHMS technology for manifold applications and have realized immense benefits. The use of this technology is still in nascent stages among many developing countries (Sanjog et al., 2012 c) like India. Manuscripts published under various categories based on work performed in India are described below. During review of literature it was observed that there is no published literature regarding application of DHM in investigations of the shop-floor workstations in small and medium scale injection-molded plastic furniture manufacturing industries till date.

4.6.5.1 Application oriented

Applications of DHMS dealt with human engineering evaluation of workstations in aviation (Pinto and Taneja, 2005), work posture analysis of foundry men through rapid upper limb assessment (Mohan et al., 2008), the interior design of a long haul truck cabin for improved human wellbeing (Powar et al., 2009), design the spatial layout of equipment in playground for primary school children (Karmakar, 2011 b), ingress-egress of an army vehicle in a simulated environment from ergonomics perspective (Karmakar et al., 2011 a), the anthropometric size measurement of Indian driving population (Kulkarni et al., 2011), reconstructing a solid model from 2d scanned images of biological organs for finite element simulation (Kumara, 2011), modeling for anthropometry (Dasgupta et al., 2012), case study for vision analysis of pilots in jet aircraft (Karmakar et al., 2012), three dimensional whole body scanning (Kulkarni et al., 2012), working posture examination and improvement in cast house workstation (Kumar and Das, 2012), design of playground equipment (Kumar et al., 2012), automotive ergonomics for urban warfare vehicle (Ranjan et al., 2012), evaluation of a shoe rack concept product (Sanjog et al., 2012 a), occupant packaging (Ganesh, 2013), road accident reconstruction (Pal et al., 2013), proactive ergonomics for a product design innovation (kumar et al., 2013), evaluation of manual material handling in bearing manufacturing system and redesign of the workstation (Rajesh and Maiti, 2013), exploration of ergonomic problems and design solutions in a drinking cup (Patnaik, 2014), ergonomic intervention and evaluation of conference hall design (kumar and Karmakar, 2014), seat design of a bus (Chanda and Banerjee, 2014), ergonomic evaluation of manually operated pineapple peeling machine (Kumar and Chakrabarti, 2014), the postural assessment of a submersible pump assembly work (Sekaran et al., 2014) and ergonomic workplace evaluation for assessing occupational risks in multistage pump assembly (Nishanth et al., 2014).

4.6.5.2 Research and development initiatives

Articles categorized under research and development initiatives for DHM are scant. Available papers / abstracts include research activities related to hand postures inspired from classical ‘mudras’ (Vipin and Sen, 2008), task dependent boundary mannequins in statistical DHM (Reddy and Sen, 2008), the comparative study of human model constructions in different 3D digital human modeling software (Karmakar, 2010), 3D reconstruction of biological organs from 2D image sequences (Kumara, and Ghosal, 2010), 3D physiological CAD model in pedagogy of physiology and medical sciences (Karmakar et al., 2011 c), a vision modeling framework (Vinayak, and Sen, 2012), relation based posture modeling (Reddi and Sen, 2013) and measurement and representation of range of motion of body joints on unit cube using electromagnetic trackers (Moya et al., 2011).

4.6.5.3 Review based

Few review articles have also been published. Review articles addressed topics concerning DHMS in secondary manufacturing (Sanjog et al., 2012 b), DHM aided investigations in manufacturing shop-floor with reference to industrially developing countries (Sanjog et al., 2012 c), industry specific applications of DHM (Sanjog et al., 2012 d), CAD in DHM for human computer interaction assessment (Mukhopadhyay et al., 2012), DHM approach in ergonomic evaluations (Rajput et al., 2013), virtual ergonomic evaluation of the tractor operator's workplace (Patel et al., 2013 a), applications of DHM in agricultural engineering (Patel et al., 2013 b), virtual human modeling and simulation in textile industry (Kumar et al., 2014), research towards achieving high fidelity evaluations using DHM (Reddi et al., 2014) and virtual ergonomics for aviation and aerospace industries (Sanjog et al., 2015 a).

4.7 Work study

An initial task analysis should be performed to understand the nature of work performed / to be performed (Pheasant and Haslegrave 2006). Work study (the term used for method study and work measurement) is the assessment of human work in all its contexts, and it generally involves the systematic investigation of all the factors which affect the efficiency and economy of the work being considered for making improvements (Bureau of Indian Standards, 2002). Method study concerns with methodical recording and critical assessment of existing and proposed ways of doing a job and it is used as a means of developing and applying easier and more effective work methods (Bureau of Indian Standards, 2002). The aim of work method design is to eliminate unnecessary work, combine operations, change the sequence of operations and simplify unnecessary operations (Barnes, 1980). Work measurement techniques are employed to ascertain the time for a qualified worker to carry out a specific job at a definite level of performance (Bureau of Indian Standards, 2002).

4.7.1 Method study - fundamentals of measurement

Method study concerns with analyzing the movements of the human body while working; with the aim of eliminating unnecessary motions, minimizing fatigue and enabling better synchronization of efforts (Bureau of Indian Standards, 2002). The aim of method study is to discover the preferred method by analyzing the motions employed by the worker in carrying out an operation (Barnes, 1980). This will ultimately result in the elimination of all avoidable motions and organize the residual indispensable movements in the best sequence which is the preferred method.

4.7.2 Work measurement - fundamentals of measurement

Work measurement involves techniques like time study, synthesis, predetermined motion time standards, estimating, analytical estimating, comparative estimating, time ladder, activity sampling (ratio-delay study, observation ratio study snap-reading method, random observation method, work sampling) rated activity sampling, production study and synthetic data (Bureau of Indian Standards, 2002). Time study can also be referred as a subset of work measurement techniques applied in situations where human effort is necessary and it is used to regulate human time to some conception of a standard level of performance (Mundel and Danner, 1994). It is important to note that time study technique can be employed not only for determining the work content and standard time required for completing a particular job but also as a tool for facilitating method improvement (Bureau of Indian Standards, 1995). The series of different elements essential to complete a job or make a production unit comprises a work cycle (Bureau of Indian Standards, 1995). The time taken to complete an element or combination of elements obtained by the direct measurement method is known as observed time and cycle time encompasses the total time taken to complete the elements comprising the work cycle (Bureau of Indian Standards, 2002). Direct time study (intensive sampling) is a method wherein the performance of a task is directly observed continuously for a limited period of time and this technique is employed primarily for evaluating a repetitive task / work (Mundel and Danner, 1994).

Bureau of Indian Standards, (1995) also has laid down the guidelines for calculating the number of cycles necessary to be timed. The number of cycles to be timed can be determined either by the use of statistical method or the conventional method. For the statistical method the number of cycles to be timed is calculated using a formula (Bureau of Indian Standards, 1995) based on values obtained from a certain number of preliminary readings. The formula is used to calculate the sample size for 95.45 % confidence level and a margin of error of ±5 % which are the commonly used values (Bureau of Indian Standards, 1995; Kanawaty, 1992).

However, since a given work cycle is a collection of several work elements different sample sizes will be calculated for each element within a specified work cycle which makes the whole process burdensome unless the elements exhibit approximately the same average time which is highly unlikely. A consensus to this effect can be achieved by determining the sample size accounting it on the element which calls for the largest sample size (Bureau of Indian Standards, 1995; Kanawaty, 1992). Therefore for the sake of simplicity in calculations most of the companies adopt a conventional guide (table 4.1) for determining the number of cycles to be timed depending on the total number of minutes per cycle (Bureau of Indian Standards, 1995; Kanawaty, 1992).

Table 4.1

Conventional method for determining number of cycles to be timed

Minutes per cycle	up to 0.10	to 0.25	to 0.50	to 0.75	to 1.0	to 2.0	to 5.0	to 10.0	to 20.0	to 40.0	over 40.0
Number of cycles recommended	200	100	60	40	30	20	15	10	8	5	3

(adopted from Bureau of Indian Standards, 1995)

The cumulative timing method is the most commonly used method of stopwatch timing (Bureau of Indian Standards, 1995). The cumulative timing method provides reasonable accuracy and even if some element times are missed by an inexperienced observer the overall time for the study under consideration will not be affected (Bureau of Indian Standards, 1995).

The detailed uses of time study, which include determination of labor and equipment requirements, determining the number of equipment which a person may operate, balancing the work of crews, setting schedules, setting labor standards, determination of supervisory objectives and setting of piece prices / wage incentives (Mundel and Danner, 1994) are beyond the scope and stated aim of present research work.

Productivity improvement, comparing and developing efficient work methods may be addressed with the help of standard times (Mundel and Danner, 1994). Time study technique can also be employed as a tool for facilitating method improvement (Bureau of Indian Standards, 1995). Occurrence of work related musculoskeletal disorders are influenced by work pace, work schedule and work-rest cycle among other factors like the design of equipment and workstations (Carayon et al., 1999). Observed operator cycle times before and after suitable ergonomic investigations and design interventions can serve as indicators for reduction in work pace without compromising on productivity in present research work.

A qualified worker (one who has acquired the skill, knowledge and other attributes to carry out the work in hand to satisfactory standards of quality and safety) should be timed while performing the job (Kanawaty, 1992). If more than one worker is doing the same operation, the time study analyst should time one or more operators, whereas if all the workers are found adopting the same method for a specific job and a difference in task completion time is observed then the operator performing the job closely to the normal pace should be timed (Barnes, 1980).

4.8 Statistical techniques for data analysis

In present study sample sizes are small and further the collected data did not follow normal distribution. Hence non-parametric statistics techniques which are used for small samples, nominal, ordinal and non-normal distributions (Das and Das, 2004) were used. Techniques like Mann-Whitney U test and Chi square test were employed to analyze and interpret collected data using SPSS v.20.0 (IBM, USA) software.

4.9 Aim

To identify physical, psychosocial and subjective workload risk factors; in blending, granulator and injection-molding workstations of the existing small and medium scale plastic processing industries and propose context specific design interventions.

To accomplish the stated aim, the present research endeavor has been divided into four phases.

4.10 Phase -1

This phase mainly focused on recording and categorizing of work activities, working posture assessments for identifying the need for design intervention in the existing workstations (blending, granulator and injection-molding).

4.10.1 Methodology

4.10.1.1 Selection of factories, workstations and workers for survey

(Refer chapter II; section 2.7.1)

4.10.1.2 Recording and categorizing of work activities (blending, granulator and injection molding workstations)

Contextual knowledge is strongly recommended for virtual investigations featuring DHM simulations (Dukic et al. 2002). Continuous videography was not permitted by factory management. Therefore, work activities performed in the workstations were photographed for investigations. The selected working postures represented most of the crucial work elements performed manually in a typical work cycle.

Blending workstation

The blending workstation and the major work activities (represented by selected working postures) in the blending workstation are shown in figure 4.1.

Figure 4.1 Selected working postures in the blending workstation

Granulator workstation

The granulator workstation and the major work activities (represented by selected working postures) in the granulator workstation are shown in figure 4.2.

Figure 4.2 Selected working postures in the granulator workstation

Injection-molding workstation

The major work activities (represented by selected working postures) in the injection-molding workstation are shown in figure 4.3.

Figure 4.3 Selected working postures in the injection-molding workstation

4.10.1.3 Working posture assessment

The postural assessment tools namely, Ovako Working Posture Assessment System (OWAS) (Karhu et al., 1977) and Rapid Entire Body Assessment (REBA) (Hignett and McAtamney, 2000) for identifying poor posture and determination of action categories for harmful effect on musculoskeletal system were utilized for evaluating the selected working postures. Since continuous video recording of work activities was not permitted by factory managements, the evaluation of relative proportion of postures in terms of time in OWAS (Matitila and Vilkki, 1998) was not possible. Therefore, the classification under OWAS methodology to identify poor posture and determination of action categories for the harmful effect on musculoskeletal system was performed based on momentary observations. OWAS technique was employed first to understand the overall scenario of the awkward posture among the workers during various activities. As there are some limitations (the absence of neck and elbows / wrist assessments, no separation of right and left upper extremities) in OWAS technique (OWAS, 2009; Battini et al., 2011), REBA technique of postural assessment was used subsequently for drawing clear inferences. REBA has been used for investigating material handling operations and face validity of REBA was established using numerous work postures from health care, manufacturing and electricity industries (McAtamney and Hignett, 2005). OWAS action categories for prevention of musculoskeletal disorders and REBA methodology for determination of risk level and action to be taken were utilized as guidelines for investigating and categorizing working postures.

4.10.1.4 Creation of digital human models and rendering of comfort angles

Non-availability of the Indian anthropometric data base of factory workers employed in the plastic processing industries was observed during literature review. Therefore, the civilian anthropometric database of adult Indian male population (Chakrabarti, 1977) was utilized to build the digital human models for assessments. The smallest, average and largest dimensional adult Indian male population was represented by 5^{th} p, 50^{th} p and 95^{th} p DHM respectively. Comfort angles were imparted on the digital human models. Comfort angles for different body segments were adopted and suitably adjusted from published literature (Rebiffé, 1966;

MacLeod, 2000; Tilley, 2002). The uncomfortable range of movement was given 'red' color, while 'green' color was used to represent the comfortable range with respect to the body segments.

4.10.1.5 Creation of digital mockup of shop-floor workstations

The mechanical design feature of DELMIA (V5R19) digital human modeling software was used to generate CAD model of the existing shop-floor (blending, granulator, injection-molding) workstations. The dimensions of the shop-floor workstations were measured at the factory site.

4.10.1.6 Interfacing of digital human models with the virtual workstations (blending, granulator and injection-molding workstations)

Proper interfacings of digital human models with the CAD models of shop-floor workstations (blending, granulator and injection-molding) featuring selected working postures (figure 4.4, 4.5 and 4.6) was achieved using ergonomics design and analysis feature of DELMIA software. The CAD model of the shop-floor workstation and digital human models were interfaced on a 1:1 scale. This was done to impart accurate investigations, as workstation dimensions were in exact proportion with the digital human model dimensions. The existing workstation and work activities were evaluated using digital human models representing 5th p, 50th p and 95th p Indian adult males for identifying the postural load. Visual representation of virtual evaluation considering the example of 50th p male digital human model is shown in figures 4.4, 4.5 and 4.6.

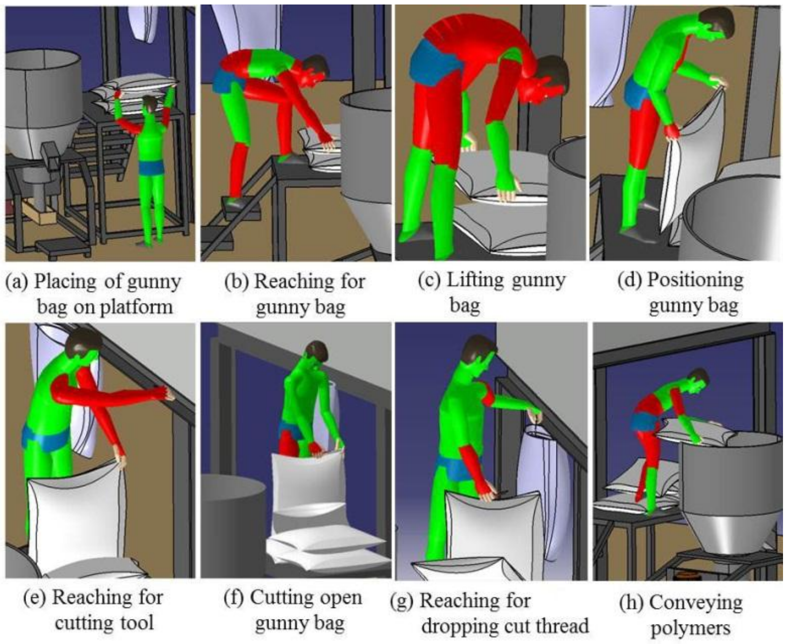


Figure 4.4 Virtual representation of working postures in the blending workstation

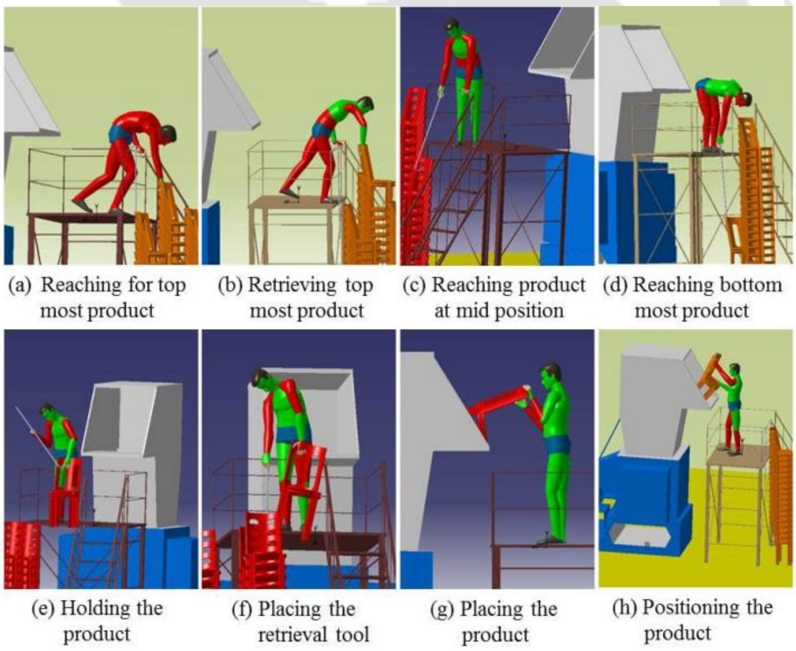


Figure 4.5 Virtual representation of working postures in the granulator workstation

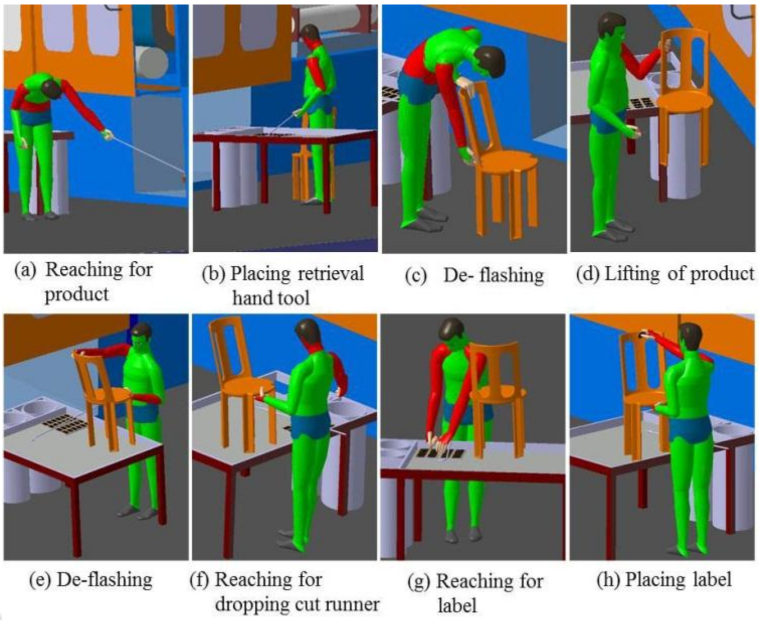


Figure 4.6 Virtual representation of working postures in the injection-molding workstation

4.10.1.7 Spinal load analysis

The mechanical load on lumbar spine is considered as a contributing factor to many disorders of the back (Chaffin and Andersson, 1991). The compressive forces (generated in L4-L5 lumbar spine due to mass of body, load acting on hand and trunk) have an allowable limit (safe cut off limit) of 3433 N and maximum permissible limit of 6376 N as recommended by NIOSH (Leyland, 2008). A safe limit of 500 N with 1000 N as maximal permissible limit was suggested by University of Waterloo ergonomic research group towards joint shear (Leyland, 2008). Biomechanics single angle action analysis feature in the DELMIA software was used to perform the spinal load analysis.

4.10.1.8 Work study

Two symbols are used for constructing the operation charts. A small circle is used for indicating transportation (moving hand to grasp an object) while a larger circle represents actions like grasping, positioning, using, or releasing an object / article (Barnes, 1980). Method study using left and right hand operation chart was used to visualize the work activities. The conventional method for determining the number of cycles to be timed using stopwatch (for timing individual operator work cycle time) adopting direct time study (intensive sampling) procedure was used for the time study investigations before and after the design modifications.

4.10.2 Observations

4.10.2.1 OWAS, REBA scores and spinal load analysis (blending, granulator and injection-molding workstations)

OWAS and REBA scores (table 4.2, 4.3 and 4.4) for working postures were computed for the individual workers pictured in figure 4.2, 4.2 and 4.3 for shop-floor workstations. Spinal load analysis (at L4 - L5 segments) with respect to the selected working postures (figure 4.4, 4.5 and 4.6) was done for 5^{th} p, 50^{th} p and 95^{th} p digital human models; the compression and joint shear values are given below (table 4.2, 4.3 and 4.4).

Blending workstation

The OWAS, REBA scores (figure 4.4) and spinal load analysis for selected working postures in the blending workstation is shown in table 4.2.

Table 4.2

OWAS, REBA scores and spinal load analysis (blending workstation)

Posture	OWAS	REBA (Rt)	REBA (Lt)	L4 - L5 Spine Limits Range (Newton)					
				Digital Human Models					
				5^{th} p		50^{th} p		95^{th} p	
	Action category	Score	Score	Compression limits	Joint Shear limits	Compression limits	Joint Shear limits	Compression limits	Joint Shear limits
a	1	7	7	673 - 6048	1 - 229	1683 - 6847	3 - 140	1710 - 7089	2 - 300
b	3	11	11						
c	3	10	10						
d	2	7	7						
e	1	7	4						
f	1	3	3						
g	1	4	4						
h	3	11	11						

Legends: Rt - Right body side; Lt - Left body side

Granulator workstation

The OWAS, REBA scores (figure 4.5) and spinal load analysis for selected working postures in the granulator workstation is shown in table 4.3.

Table 4.3

OWAS, REBA scores and spinal load analysis (granulator workstation)

Posture	OWAS	REBA (Rt)	REBA (Lt)	L4 - L5 Spine Limits Range (Newton) Digital Human Models					
				5^{th} p		50^{th} p		95^{th} p	
	Action category	Score	Score	Compression limits	Joint Shear limits	Compression limits	Joint Shear limits	Compression limits	Joint Shear limits
a	2	9	6	458 - 1995	21 - 145	1328 - 4023	43 - 168	1295 - 3172	21 - 160
b	2	8	6						
c	2	4	6						
d	2	8	5						
e	2	9	9						
f	2	9	8						
g	1	2	4						
h	2	3	6						

Legends: Rt - Right body side; Lt - Left body side

Injection-molding workstation

The OWAS, REBA scores (figure 4.6) and spinal load analysis for selected working postures in the injection-molding workstation is shown in table 4.4.

Table 4.4

OWAS, REBA scores and spinal load analysis (injection-molding workstation)

Posture	OWAS	REBA (Rt)	REBA (Lt)	L4 - L5 Spine Limits Range (Newton)					
				Digital Human Models					
				5^{th} p		50^{th} p		95^{th} p	
	Action category	Score	Score	Compression limits	Joint Shear limits	Compression limits	Joint Shear limits	Compression limits	Joint Shear limits
a	3	6	8	357 - 1441	24 - 91	859 - 3780	12 - 153	576 - 3068	17 - 152
b	1	5	2						
c	2	10	10						
d	1	2	5						
e	1	7	2						
f	1	4	2						
g	1	8	8						
h	1	6	1						

Legends: Rt - Right body side; Lt - Left body side

4.10.2.2 Visualization of body segments in comfortable and uncomfortable range of motion

Proper interfacings of digital human models with the CAD models of shop-floor workstations (blending, granulator and injection-molding) and color coding helped in visualizing the body segments occupying uncomfortable positions (within their range of movement) while performing the work activities (figure 4.4, 4.5 and 4.6).

4.10.2.3 Operation chart of work elements observed at the existing shop-floor workstations (blending, granulator and injection-molding workstations)

Blending workstation

The left and right hand operation chart for work elements in a work cycle in the existing blending workstation is shown below (table 4.5).

Table 4.5

Operation chart for work elements in a work cycle observed in the existing blending workstation

Left hand	Symbol	Symbol	Right hand
Position gunny bag over platform	O	O	Position gunny bag over platform
Release grip on gunny bag	O	O	Release grip on gunny bag
Reach for gunny bag	o	o	Reach for gunny bag
Grasp gunny bag	O	O	Grasp gunny bag
Lift gunny bag	o	o	Lift gunny bag
Position gunny bag	O	O	Position gunny bag
Grasp gunny bag	O	O	Reach for cutting tool
Grasp gunny bag	O	O	Grasp cutting tool
Grasp gunny bag	O	O	Position cutting tool for cutting open gunny bag
Grasp cut thread	O	o	Cut open gunny bag
Carry cut thread to bin	o	O	Grasp cutting tool
Release cut thread	O	--	--
Reach for gunny bag	o	o	Transport cutting tool
Grasp gunny bag	O	O	Release cutting tool
--	--	o	Reach for gunny bag
--	--	O	Grasp gunny bag
Lift gunny bag	o	o	Lift gunny bag
Position gunny bag over machine	O	O	Position gunny bag over machine
Convey polymers into blending machine	o	o	Convey polymers into blending machine

Legends: o – transportation (moving hand to grasp the article); O – actions (grasping, positioning, using or releasing the article) (adopted from Barnes, 1980)

Granulator workstation

The left and right hand operation chart for work elements in a work cycle in the existing granulator workstation is shown below (table 4.6).

Table 4.6

Operation chart for work elements in a work cycle observed in the existing granulator workstation

Left hand	symbol	symbol	Right hand
Reach for railing	o	o	Reach for retrieval hand tool on platform railing
Grasp railing	O	O	Grasp retrieval hand tool
--	--	o	Lift retrieval hand tool
--	--	o	Change position and orientation of retrieval hand tool
--	--	o	Reach for chair with retrieval hand tool
Release grip on railing	O	O	Position retrieval hand tool on chair
Reach for chair		o	Lift chair
Grasp chair	O	O	Release retrieval hand tool from chair
--	--	o	Change orientation and position retrieval hand tool
--	--	o	Transport retrieval hand tool to railing
--	--	O	Release retrieval hand tool over railing
--	--	o	Reach for chair
--	--	O	Grasp chair
Carry chair towards grinding slot	o	o	Carry chair towards grinding slot
Position chair on grinding slot	o	o	Position chair on grinding slot
Lift chair for final push into grinding machine	o	o	Lift chair for final push into grinding machine
Push chair into grinding machine	o	o	Push chair into grinding machine

Legends: o – transportation (moving hand to grasp the article); O – actions (grasping, positioning, using or releasing the article) (adopted from Barnes, 1980)

Injection-molding workstation

The left and right hand operation chart for work elements in a work cycle observed in the existing injection-molding workstation is shown in table 4.7.

Table 4.7

Operation chart for work elements in a work cycle observed in the existing injection-molding workstation

Left hand	symbol	symbol	Right hand
--	--	O	Hold De-flashing hand tool
--	--	o	Reach for retrieval tool on work table
--	--	O	Grasp retrieval tool
--	--	o	Transport retrieval tool towards product
--	--	O	Position retrieval tool on product
--	--	O	Retrieve finished product
Reach for finished product	o	--	--
Grasp finished product	O	o	Transport retrieval tool to work table
--	--	o	Place retrieval tool on table
--	--	O	Release grasp on retrieval tool
--	--	o	Reach for finished product
--	--	O	Position cutting tool on finished product
--	--	O	De-flash finished product
Lift finished product	o	--	--
Transport finished product to work table	o	--	--
Position finished product on work table	O	o	Reach for finished product
Grasp finished product	O	O	Position cutting tool on finished product
--	--	O	De-flash finished product
--	--	O	Grasp cut runner
--	--	o	Reach for dropping runner
--	--	O	Release cut runner into collector
--	--	o	Reach for finished product
--	--	O	De-flash finished product
Reach for product label chart 1on work table	o	o	Reach for product label 1on work table
Hold product label chart 1	O	O	Remove product label 1
Release product label chart 1	O	--	--
Reach for finished product	o	o	Reach for finished product
Grasp finished product	O	O	Stick product label 1on finished product
Release grip on finished product	O	--	--
Reach for product label chart 2 on work table	o	o	Reach for product label 2 on work table
Hold product label chart 2	O	O	Remove product label 2
Release product label chart 2	O	--	--
Reach for finished product	o	O	Reach for finished product
Grasp finished product	O	O	Stick product label 2 on finished product
--	--	o	Reach for finished product
--	--	O	Grasp finished product
Remove finished product form work table	O	O	Remove finished product form work table

Legends: o – transportation (moving hand to grasp the article) ; O – actions (grasping, positioning, using or releasing the article) (adopted from Barnes, 1980)

4.10.3 Discussion

4.10.3.1 Blending workstation

The participants in the blending workstation as well as the control group were of similar age, standing height, weight and work experience (table 2.3; chapter 2; section 2.8.1). It was observed that number of participants suffering from discomfort during working was 5 in the control group, whereas in experimental group, the number of sufferers was 25. Statistical analysis (Chi square test) of data revealed that experimental group was significantly higher (χ^2 - 12.482; P $\leq$ 0.001) when compared with the control group in terms of percentage of participants suffering from discomfort during work. Although participants of experimental group were of similar characteristics (age, standing height, weight and work experience) as that of the control group, higher prevalence of symptoms of musculoskeletal ailments in various body parts among participants of experimental group (table 2.4; chapter 2, section 2.8.3) were due to differences in occupational activities which in turn were influenced by working postures, work methods, manual load handling and workstation design / layout.

REBA analysis showed presence of risky work postures which needed to be changed (table 4.2). Workstation layout, visual demands of job, design of tools and equipment's, anthropometric characteristics of worker and work methods are the main reasons for inducing awkward working posture (at trunk, neck and shoulders) and further determines positioning of the workers body when performing a task (Keyserling et al., 1992). Working platform used by the worker to store the gunny bags before conveying into the blending machine did not meet the requisite design criteria specified by researchers and organizations with respect to space availability for working person and other design requirements (railing, toe board and tool holder) (Pheasant and Haslegrave, 2006; Bureau of Indian Standards, 1992a; Bureau of Indian Standards, 1992b). Physical mismatch between the anthropometry of worker and workstation (working platform) design dimensions resulted in adoption of awkward working postures (figure 4.1, table 4.2). The location for placing cutting tool, collector / bin for dropping cut thread also resulted in the extensive reaching and subsequent adoption of undesirable working posture (figure 4.1). The working postures were also characterized by the presence of certain body parts in the uncomfortable range of motion as indicated by the presence of red color in corresponding body segments (figure 4.4).

Bio-mechanical analysis using digital human modeling software indicated that the compressive loads for 50th p and 95th p were above the maximum permissible limits whereas for 5th p it was found to be above safe limits for some working postures (table 4.2). The joint shear values for 5th p, 50th p and 95th p were below safe limits (table 4.2) for all the working postures considered in the present study. Manual lifting of gunny bags (25 kg in weight) many times in a typical work cycle was observed (figure 4.1). The revised NIOSH lifting equation of 1991 reduced the load constant (maximum recommended weight under ideal lifting conditions) from 40 kg to 23 kg (Elfeituri and Taboun, 2002; Colombini et al., 2012). Method study aided by the operation chart helped to understand, scrutinize and record the work elements in a work cycle in the form of right and left hand working motions (table 4.5).

4.10.3.2 Granulator workstation

Comparison (using Mann Whitney U test) of variables (age, standing height, weight and work experience) between granulator workstation workers and control group indicated that there were no significant differences between workers of granulator workstation and control group (table 2.3; chapter 2; section 2.8.1). This indicates that participants in experimental group as well as control group were of similar age, standing height, weight and work experience. It was observed that number of participants suffering from body parts discomfort during working was 5 in the control group, whereas numbers of sufferers was 10 in the experimental group. Statistical analysis (Chi square test) of data revealed that the experimental group was significantly higher ($\chi 2$ – 8.507; $P < 0.05$) when compared with the control group in terms of percentage of participants suffering from discomfort during work. Although workers of granulator workstation were of similar characteristics (age, standing height, weight and work experience) as that of the control group, higher prevalence of musculoskeletal ailments in various body parts among participants of experimental group were due to differences in occupational activities; which in turn were influenced by working posture, work methods, manual load handling and workstation design / layout.

The L4-L5 spine details for working postures (figure 4.5) are shown in table 4.3. The compression values for certain working postures exceeded safe cut off limits for 50^{th} p digital human model while joint shear values (for 5^{th}, 50^{th} and 95^{th} digital manikins) were less than safe limits for all postures considered.

A detailed motion study for observed activities (work elements in a work cycle) in current granulator workstation using operation chart (Barnes, 1980) was prepared. The left and right hand operation chart before suggesting modifications to the existing workstation and work method design is shown in table 4.6.

4.10.3.3 Injection-molding workstation

It was observed that the number of participants suffering from discomfort in body parts while working was 5 in the control group, whereas number of sufferers was 43 in experimental group. Statistical analysis (Chi square test) of data revealed that experimental group was significantly higher ($\chi2$ - 20.945; $P \leq 0.001$) when compared with the control group in terms of percentage of participants suffering from discomfort during work. Although participants of the experimental group were of similar characteristics (age, standing height, weight and work experience) as that of the control group, higher prevalence of musculoskeletal ailments in various body parts among participants of the experimental group were due to differences in occupational activities; which in turn were influenced by working posture, work methods and workstation design / layout.

Rapid Entire Body Assessment (REBA) showed presence of risky work postures which needed to be changed (table 4.4). Workstation layout, design of equipment's and tools, anthropometric characteristics of worker, work methods are the main reasons for inducing awkward working posture at trunk, neck and shoulders and further determines positioning of workers' body when performing a task (Keyserling et al., 1993; Pheasant and Haslegrave, 2006). Work activities (figure 4.3; placing retrieval tool, de-flashing keeping product on floor and reaching activities) characterized by an extensive reach also contributed to risky work postures. Deviated work postures among various other risk factors contribute towards development of musculoskeletal disorders (Finneran and O'Sullivan, 2010). It is widely accepted that extremes of posture are associated with upper-extremity musculoskeletal disorders among workers (Gerr et al., 2014). Physical mismatch between workers anthropometry, worktable and product dimensions and work methods resulted in prevalence of awkward work postures (figure 4.3, table 4.4) with certain body segments in uncomfortable range of motion (indicated by red color, figure 4.6).

Spinal load analysis using digital human modeling software indicated that the compressive forces exceeded safe limits (but within maximum permissible limits) for 50^{th} p digital human model while evaluating selected working postures whereas shear forces were within safe limits (table 4.4). Compression and shear forces generated at L4 - L5 segments in selected working postures were within safe limits (table 4.4) for 5^{th} p and 95^{th} p digital human models. The left and right hand operation chart before suggesting modifications to the existing workstation and work method design is shown in table 4.7.

4.11 Phase – 2

This phase focused on investigating the status of psychosocial work environment among selected workers in shop-floor workstations and its comparison with the control group employees.

4.11.1 Methodology

4.11.1.1 Selection of questionnaire for investigating psychosocial work environment

The Copenhagen Psychosocial Questionnaire (COPSOQ) II – medium version (Kristensen et al., 2005; The Copenhagen Psychosocial Questionnaire II - medium version, 2012) **(Appendix VI)** was used to investigate the psychosocial work environment in the present research. The COPSOQ (Kristensen et al., 2005) which is a validated questionnaire incorporates a broad range of up-to-date leading concepts and theories (Nuebling et al., 2013). It is also reported that detailed information is given by Copenhagen Psychosocial Questionnaire (Arvidsson, 2008). Majority of the questions were taken from already existing, well approved and validated instruments, like “Setterlind Stress Profile” (Setterlind and Larsson, 1995) and the “Job Content Questionnaire” (Karasek et al., 1998) and from a large study “Whitehall II Study”

(Marmot et al., 1991) and only a small portion of items has been newly developed (Nuebling et al., 2013).

Each scale in the COPSOQ II scale has 3-4 questions (items) in order to give sufficient reliability and precision (COPSOQ II, 2007). High scores relate to high values on respective dimensions and in majority of cases high scores indicate being good or healthy. But exceptions to this can be found in quantitative demands; work pace, emotional demands, role conflicts, work-family conflict, burnout, stress and sleeping problems (COPSOQ II, 2007) and these should be interpreted accordingly. Also a few of the questions are scored with 'reversed scoring' which is indicated at all the relevant places (COPSOQ II, 2007). Scores of items / dimensions may be grouped into three levels (based on range of the score) namely, 0 - 40, 40 - 60 and 60 - 100 (Kristensen, 2001). Apprehensions expressed by Muhonen and Torkelson (2003) that gender differences could play an important role in the workers/employees perceptions of psychosocial work environment does not apply in present research work as all the subjects under consideration were male.

4.11.2 Observations

4.11.2.1 Blending Workstation

The results of the psychosocial survey using COPSOQ medium size questionnaire pertaining to workers in the blending workstations and control group employees; and comparisons are given below (table 4.8).

Table 4.8

Status of psychosocial work environment among the blending workstation workers and comparison with control group

Dimensions	Blending Workstation (BW) (n=29) (Mean)	Control Group (CG) (n=15) (Mean)	Comparisons (Mann-Whitney U test) BW Vs. CG
Quantitative Demands	15.7	33.0	*
Tempo, Work Pace	28.7	45.0	*
Emotional Demands	32.8	44.6	*
Influence At Work	39.2	56.7	*
Possibilities For Development (Skill Discretion)	54.3	78.7	*
Meaning Of Work	75.3	84.4	*
Commitment To The Workplace	56.9	73.3	*
Predictability	70.3	77.5	NS
Rewards	64.4	77.5	*
Role Clarity	89.7	80.0	NS
Role Conflicts	25.7	49.2	*
Quality Of Leadership	59.5	75.0	*
Social Support From Colleagues	52.6	70.0	*
Social Support From Supervisors	61.5	75.6	*
Social Community At Work	83.3	80.0	NS
Satisfaction With Work – Job Satisfaction	61.5	67.8	*
Work Family Conflict	36.5	30.5	NS
Horizontal Trust	77.6	53.9	*
Vertical Trust	78.2	67.5	NS
Justice And Respect	56.9	69.2	*
Self-Rated Health	56.9	60.0	NS
Sleeping Troubles	14.2	33.7	*
Burnout	29.6	33.3	NS
Stress	5.6	28.7	*

Legends: NS – No significant difference ($p \geq 0.05$); * - Significant difference ($p \leq 0.05$)

4.11.2.2 Granulator Workstation

The results of the psychosocial survey using COPSOQ medium size questionnaire pertaining to workers in the granulator workstations and control group employees; and comparisons are given below (table 4.9).

Table 4.9

Status of psychosocial work environment among the granulator workstation workers and comparison with control group

Dimensions	Granulator Workstation (GW) (n=10) (Mean)	Control Group (CG) (n=15) (Mean)	Comparisons (Mann-Whitney U test) BW Vs. CG
Quantitative Demands	18.1	33.0	*
Tempo, Work Pace	16.7	45.0	*
Emotional Demands	25.0	44.6	*
Influence At Work	46.8	56.7	*
Possibilities For Development (Skill Discretion)	62.5	78.7	*
Meaning Of Work	73.3	84.4	*
Commitment To The Workplace	53.1	73.3	*
Predictability	72.5	77.5	NS
Rewards	70.0	77.5	NS
Role Clarity	95.0	80.0	*
Role Conflicts	5.6	49.2	*
Quality Of Leadership	79.4	75.0	NS
Social Support From Colleagues	65.0	70.0	NS
Social Support From Supervisors	69.2	75.6	NS
Social Community At Work	94.2	80.0	NS
Satisfaction With Work – Job Satisfaction	55.0	67.8	*
Work Family Conflict	26.6	30.5	NS
Horizontal Trust	82.5	53.9	*
Vertical Trust	81.3	67.5	*
Justice And Respect	65.6	69.2	NS
Self-Rated Health	65.0	60.0	NS
Sleeping Troubles	8.1	33.7	*
Burnout	18.7	33.3	NS
Stress	2.5	28.7	*

Legends: NS – No significant difference ($p \geq 0.05$); * - Significant difference ($p \leq 0.05$)

4.11.2.3 Injection-molding workstation

The results of the psychosocial survey using COPSOQ medium size questionnaire pertaining to workers in the injection-molding workstations and control group employees; and comparisons are given below (table 4.10).

Table 4.10

Status of psychosocial work environment among the injection-molding workstation workers and comparison with control group

Dimensions	Granulator Workstation (GW, n=10) (Mean)	Control Group (CG, n=15) (Mean)	Comparisons (Mann-Whitney U test) BW Vs. CG
Quantitative Demands	34.2	33.0	NS
Tempo, Work Pace	85.3	45.0	*
Emotional Demands	42.1	44.6	NS
Influence At Work	45.9	56.7	*
Possibilities For Development (Skill Discretion)	69.0	78.7	*
Meaning Of Work	72.3	84.4	*
Commitment To The Workplace	57.9	73.3	*
Predictability	69.3	77.5	NS
Rewards	59.6	77.5	*
Role Clarity	85.7	80.0	NS
Role Conflicts	25.1	49.2	*
Quality Of Leadership	58.3	75.0	*
Social Support From Colleagues	57.9	70.0	*
Social Support From Supervisors	62.9	75.6	*
Social Community At Work	77.5	80.0	NS
Satisfaction With Work – Job Satisfaction	59.2	67.8	*
Work Family Conflict	37.5	30.6	NS
Horizontal Trust	66.1	53.9	*
Vertical Trust	71.3	67.5	NS
Justice And Respect	56.8	69.2	*
Self-Rated Health	55.9	60.0	NS
Sleeping Troubles	19.6	33.7	*
Burnout	32.6	33.3	NS
Stress	9.8	28.8	*

Legends: NS – No significant difference ($p \geq 0.05$); * - Significant difference ($p \leq 0.05$)

4.11.3 Discussion

4.11.3.1 Blending Workstation

The psychosocial work environment was satisfactory for both the blending shop-floor workstation workers and the control group employees. Significant differences in mean values were observed between workers in blending workstations and the employees in the control group for various psychosocial factors (table 4.8). Blending shop-floor workers and administrative / supervisory employees perceived psychosocial stress in their respective workplaces differently. The psychosocial investigations at the blending workplace reveal that there are no serious problems with respect to the psychosocial work environment in the factories considered. Blending workstation workers were not exposed to serious psychosocial stress factors.

Therefore, attention should be paid for mitigating the risk factors like incidence of awkward working postures among workers in the blending shop-floor workstations.

4.11.3.2 Granulator Workstation

The psychosocial work environment was satisfactory for both the granulator shop-floor workstation workers and the control group employees. Significant differences in mean values were observed between workers in the granulator workstations and the employees in the control group for various psychosocial factors (table 4.9). The granulator shop-floor workers and administrative / supervisory employees perceived psychosocial stress in their respective workplaces differently in some aspects. The psychosocial investigations at the granulator workplace reveal that there are no serious problems with respect to the psychosocial work environment in the factories. The granulator workstation workers were not exposed to serious psychosocial stress factors. Therefore, attention should be paid for mitigating risk factors like incidence of awkward working postures among workers in the granulator shop-floor workstations.

4.11.3.3 Injection-molding workstation

The psychosocial work environment was satisfactory for both the injection-molding shop-floor workstation workers and the control group employees. However, the injection-molding workers reported high values for the psychosocial factor tempo (work pace). Significant differences in mean values were observed between workers in the injection-molding workers workstations and the employees in the control group for various psychosocial factors (table 4.10). The injection-molding shop-floor workers and administrative / supervisory employees perceived psychosocial stress in their respective workplaces differently in some aspects. The psychosocial investigations at the injection-molding workplace reveal that there are no serious problems with respect to the psychosocial work environment in the factories considered except for the psychosocial factor tempo (work pace). Therefore, attention should be paid to mitigating risk factors like incidence of awkward working postures and reducing tempo (work pace) among workers in the injection-molding workers shop-floor workstations.

4.12 Phase – 3

The operator workload is being increasingly assessed using subjective measures because of practical advantages (ease of implementation and non-intrusiveness) in human-machine system evaluations (Rubio et al., 2004). The subjective workload assessment for work activities was performed for shop-floor workstation (blending, granulator and injection-molding) workers (experimental group) and control group (administrative / supervisory) employees.

4.12.1 Methodology

4.12.1.1 Selection of questionnaire for investigating subjective workload

A popular method for determining subjective workload is the NASA Task Load Index (TLX) which helps in finding an overall workload score based on a weighted average of ratings using six subscales namely mental demand, physical demand, temporal demand, performance, effort and frustration level (Jung and Jung, 2001; Cao et al., 2009; Shaikh et al., 2013). NASA TLX (Hart and Staveland, 1988) is also the most widely known tool for assessing subjective workload on operator(s) working with various human–machine systems. The reliability of the NASA TLX scale is very good (r = .83) (Singh et al., 2005). NASA Task Load Index (TLX) fulfills the required criteria of a good workload assessment technique with respect to sensitivity, diagnostic capabilities, selectivity, low intrusiveness, reliability and ease of implementation (Cao et al., 2009).

The NASA-TLX is a multidimensional scale **(Appendix VII, VIII and IX)** that provides an overall or global measure of workload and also identifies specific components of workload (Tiwari et al., 2009). Based on a weighted average of ratings the NASA TLX scale provides an overall workload score (Singh et al., 2005; Singh et al., 2010 a). The NASA TLX consists of two parts namely ratings and weights while the ratings for each of the six subscales are obtained from the participants after the completion of a task (Cao et al., 2009). Three sub scales of the NASA Task Load Index (TLX) focus on the demand enforced on the person performing the task (mental, physical and temporal demand) while the emphasis of other subscales is on the interaction of the subject with the task (performance, effort and frustration level)

(Hart & Staveland, 1988; Cao et al., 2009). Each scale is assigned a numerical rating ranging from 0 to 100 (least to most taxing) and the weights are determined by the participant's choices of the subscale most relevant to workload for them from a pair of choices (Singh et al., 2005; Cao et al., 2009). Weights (ranging from 0 to 5; least to most relevant) are calculated from 15 combinatorial pairs created from the six subscales and finally the ratings and weights are then combined to calculate a weighted average for an overall workload score (Cao et al., 2009). The workload is lower if the NASA TLX index value is smaller (Kato et al., 2005). Increase in NASA-TLX scores are also associated with heavier loads due to the physical demand dimension included in the calculation of the overall assessment value (Colle and Reid, 1998).

The NASA Task Load Index (NASA TLX) questionnaire can be used to determine perceived physical and mental workload (Sealetsaa and Thatcher, 2011). NASA TLX describes the overall workload during multi task situations involving substantial physical activity although it was initially proposed to be a mental workload evaluation tool (DiDomenico and Nussbaum, 2008). NASA TLX is reported to be useful in towards research on mental workload of the human operators in multi-tasks scenarios (Singh et al., 2010 a). Various studies have suggested that NASATLX can be used as a valid tool for assessing the mental and the physical workloads of operators using a wide variety of technologies (Sealetsaa and Thatcher, 2011). Several researchers have used the NASAT LX in their work and have found it to show a significantly high validity as a tool for measuring both mental and physical workloads (Cook and Salvendy, 1999).

4.12.2 Observations

4.12.2.1 Blending workstation

The results for the subjective workload investigations using NASA – Task Load Index with respect to workers in the blending workstations and control group employees; and comparisons are given below (table 4.11).

Table 4.11

Subjective workload assessment of the blending workstation workers and comparisons

Scale title	Mean raw rating			Mean weighted rating		
	BW (n=29)	CG (n=15)	Comparisons (Mann-Whitney U test) BW Vs. CG	BW (n=29)	CG (n=15)	Comparisons (Mann-Whitney U test) BW Vs. CG
Mental demand	32.4	72.3	*	34.7	72.4	*
Physical demand	91.9	9.6	*	91.9	20.7	*
Temporal demand	32.6	14.6	*	36.3	15.9	*
Performance	14.6	10.3	NS	14.3	10.4	NS
Effort	81.9	30.0	*	82.5	30.8	*
Frustration level	6.9	15.3	*	9.1	15.8	*

Legends: NS – no significant difference ($p > 0.05$); * - significant difference ($p \leq 0.05$); BW – Blending Workstation; CG – Control Group

4.12.2.2 Granulator workstation

The results for the subjective workload investigations using NASA – Task Load Index with respect to workers in the granulator workstations and control group employees; and comparisons are given below (table 4.12).

Table 4.12

Subjective workload assessment of the granulator workstation workers and comparisons

Scale title	Mean raw rating			Mean weighted rating		
	GW (n=10)	CG (n=15)	Comparisons (Mann-Whitney U test) GW Vs. CG	GW (n=10)	CG (n=15)	Comparisons (Mann-Whitney U test) GW Vs. CG
Mental demand	7.0	72.3	*	17.5	72.4	*
Physical demand	82.0	9.6	*	82.4	20.7	*
Temporal demand	16.5	14.6	NS	16.6	15.9	NS
Performance	8.5	10.3	NS	8.5	10.4	NS
Effort	73.5	30.0	*	73.9	30.8	*
Frustration level	17.5	15.3	NS	17.5	15.8	NS

Legends: NS – no significant difference ($p > 0.05$); * - significant difference ($p \leq 0.05$); GW – Granulator Workstation; CG – Control Group

4.12.2.3 Injection-molding workstation

The results for the subjective workload investigations using NASA – Task Load Index with respect to workers in the injection-molding workstations and control group employees; and comparisons are given below (table 4.13).

Table 4.13

Subjective workload assessment of the injection-molding workstation workers and comparisons

Scale title	Mean raw rating			Mean weighted rating		
	IW (n=46)	CG (n=15)	Comparisons (Mann-Whitney U test) IW Vs. CG	IW (n=46)	CG (n=15)	Comparisons (Mann-Whitney U test) IW Vs. CG
Mental demand	21.7	72.3	*	34.3	72.4	*
Physical demand	79.9	9.6	*	80.8	20.7	*
Temporal demand	94.6	14.6	*	94.6	15.9	*
Performance	27.7	10.3	*	27.7	10.4	*
Effort	70.4	30.0	*	71.3	30.8	*
Frustration level	7.1	15.3	*	13.0	15.8	*

Legends: NS – no significant difference ($p > 0.05$); * - significant difference ($p \leq 0.05$); IW – Injection-molding Workstation; CG – Control Group

4.12 Discussion

The mean weighted ratings (for each scale title) for workers in experimental and control group were calculated using the following formula.

$$\text{Mean weighted ratings} = \frac{\sum \text{(individual raw rating x individual weight)}}{\sum \text{individual weight}}$$

4.12.1 Blending workstation

The ratings for various scale titles for the subjective workload assessments were significantly different between the experimental group (blending shop-floor workers) and the control group (administrative / supervisory employees) (table 4.11). The mean overall subjective workload for experimental group (blending workstation workers) was 60.1 and 34.6 for the control group. Significant differences ($p \leq 0.05$) were observed between the two groups with respect to the mean overall subjective workload. Physical demand and effort are rated very high by the experimental group (table 4.11). Mental demand was rated very high by the control group (table 4.11). The performance of both the experimental group and control group were good (table 4.11) as they were found to be successful in completing the tasks associated with their jobs.

The mean weighted ratings for the scale titles (except for performance) were significantly different ($p \leq 0.05$) between the experimental group (blending shop-floor workers) and control group (administrative / supervisory employees) (table 4.11). The weighted ratings were found to be high for physical demand and effort among blending workstation workers (table 4.11).

Hence, it is evident that ergonomic design interventions should primarily focus on reducing the perceived physical demand and effort among the blending shop-floor workstation workers.

4.12.2 Granulator workstation

The ratings for various scale titles for the subjective workload assessments were significantly different between experimental group (granulator shop-floor workers) and control group (administrative / supervisory employees) (table 4.12). The mean overall subjective workload for experimental group (granulator workstation workers) was 48.7 and 34.6 for the control group. Significant differences ($p \leq 0.05$) were observed between the two groups with respect to the mean overall subjective workload. Physical demand and effort are rated very high by the experimental group (table 4.12). Mental demand was rated very high by the control group (table 4.12). The performance of both the experimental group and control group were good (table 4.12) as they were found to be successful in completing the tasks associated with their jobs.

The mean weighted ratings for the scale titles (except for temporal demand, performance and frustration) were significantly different ($p \leq 0.05$) between the experimental group (granulator shop-floor workers) and control group (administrative / supervisory employees) (table 4.12). The weighted ratings were found to be high for physical demand and effort among granulator workstation workers (table 4.12).

Hence, it is evident that ergonomic design interventions should primarily focus on reducing the perceived physical demand and effort among the granulator shop-floor workstation workers.

4.12.3 Injection-molding workstation

The ratings for various scale titles for the subjective workload assessments were significantly different between experimental group (injection-molding shop-floor workers) and control group (administrative / supervisory employees) (table 4.13). The mean overall subjective workload for the experimental group (injection-molding workstation workers) was 69.3 and 34.6 for the control group. Significant differences ($p \leq 0.05$) were observed between the two groups with respect to the mean overall subjective workload. Temporal demand, physical demand and effort are rated very high by the experimental group (table 4.13). Mental demand was rated very high by the control group (table 4.13). The performance of both the experimental group and control group were good (table 4.13) as they were found to be successful in completing the tasks associated with their jobs.

The mean weighted ratings for the scale titles were significantly different ($p \leq 0.05$) between the experimental group (injection-molding shop-floor workers) and control group (administrative / supervisory employees) (table 4.13). The weighted ratings were found to be high for temporal demand, physical demand and effort among injection-molding workstation workers (table 4.13).

Hence, it is evident that ergonomic design interventions should primarily focus on reducing the perceived temporal demand, physical demand and effort among the injection-molding shop-floor workstation workers.

4.13 Phase – 4

Awkward working postures and incidences of musculoskeletal symptoms were prevalent among workers in shop-floor blending workstation. Fixtures in the workstations were found to be designed arbitrarily thus aiding the occurrence of risky, uncomfortable work postures and incidence of body parts discomfort among shop-floor workers. Generally good psychosocial work environment was prevalent in shop-floor workstations. The psychosocial investigations at the blending and granulator workplaces reveal that there are no serious problems with respect to the psychosocial work environment in the factories. Injection-molding workers reported high values for the psychosocial factor tempo (work pace). Shop-floor workers perceived the work activities / tasks to be physically demanding needing high effort. Temporal demand was reported to be very high by the workers across the injection-molding workstations. Therefore, in present phase, interventions focused on workstation designs and work method designs were attempted from an ergonomics perspective. It was considered to design conceptual workstations incorporating appropriate recommended guidelines. The workstation concepts were evaluated using digital human modeling technique to minimize awkward work postures and facilitate acceptable work methods accompanied by body segments positioned within the comfortable range of motion.

4.13.1 Methodology

The anthropometry of any defined user population is supposed to serve as a guideline for geometric design of equipment and work places to ensure man-machine compatibility as recommended by the Bureau of Indian Standards (Bureau of Indian Standards, 1991a). From common understanding, it is evident that 5th percentile female and 95th percentile male represented the extreme groups in a population which encompasses the smallest and the largest body dimensions respectively. If the workforce is dominated by a particular gender then it is appropriate to design for the predominant gender (Helander 1995). Hence, work activities in the shop-floor workstations (blending, granulator and injection-molding) were assessed and modified suitably for the male gender.

4.13.1.1 Proposed design of blending workstation along with its components

Brainstorming sessions were held with blending workstation workers, production supervisors / managers and suggestions were recorded. Revised NIOSH lifting equation of 1991 reduced the maximum recommended weight under ideal lifting conditions from 40 kg to 23 kg. Therefore, movement / transfer of gunny bags by sliding action was proposed through suitable workstation design (with help of rollers in lifting platform and work table), material handling trolley design (four wheel hand cart with rollers on top surface) and work method (use of hand tool). When a workstation is designed for taller and shorter people, a platform may be provided for shorter people (which may be brought from a storage spot when needed) to avoid height mismatches (MacLeod, 2000). The small and medium scale industries in the manufacturing sector are characterized by low level of automation particularly for material handling activities. Hence, lifting of gunny bag to the worktable on the working platform was proposed to be accomplished through a mechanism involving lifting platform, pulley, ratchet and pawl, and a drum (attached with handles) for winding the rope. Mechanical design feature of DELMIA (V5R19) digital human modeling software was used to generate CAD model of the proposed blending workstation (figure 4.7).

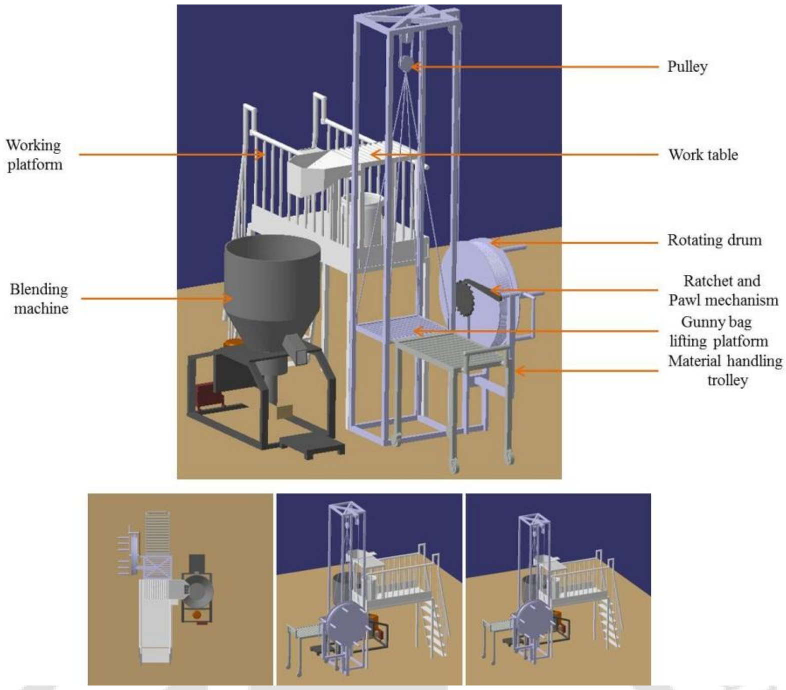


Figure 4.7 Proposed blending workstation design

The top surface of the material handling trolley (1120 mm × 670 mm) was designed to hold two gunny bags side by side. Additional gunny bags may be stacked one over other if needed. Platform surface of the material handling trolley was at a height of 1055 mm from the ground level. This height was near about the elbow height of 50^{th} p and thus will help majority of the workers to perform required work at about the elbow height which is normally recommended (Shoaf et al., 1998; Pheasant and Haslegrave, 2006). The lifting platform (704 mm × 647 mm) was designed taking into consideration the design dimensions of the gunny bag containing polymers. The lifting platform should be kept at a height of 1055 mm from the ground initially (coinciding with height of platform surface (from ground) of material handling trolley) for conveying the gunny bag by sliding action. Diameter of the handle for rotating the drum and for operating the lever (ratchet and pawl mechanism) was designed to be 55 mm. From literature sources, it was observed that the maximal handle contact area which will minimize surface stress to skin occurs on handles 50 to 60 mm in diameter (Pheasant and Haslegrave, 2006). Multiple handles were provided near the drum circumference for facilitating the worker to rotate the drum (standing comfortably at a particular location using both hands alternatively) avoiding extensive rotating actions of a particular hand. Drum diameter was designed to be at 1000 mm for reducing the number of rotations for winding the rope. Distance between center of the drum and the ground level was kept at 1301 mm for operating the rotating handles in comfortable working postures. Distance between lowest point of the handle (used for operating ratchet and pawl mechanism) and the ground level was kept at 1130 mm with the handle length being 300 mm. This will facilitate easy holding and operating the handle at about the elbow height. Railings on the working platform were at height of 900 mm from the standing surface and toe boards at a height of 100 mm were provided as recommended (Bureau of Indian Standards, 1992a). Top surface of worktable in the working platform was kept at 2650 mm from the ground level considering height of the blending machine and the need for conveying the polymers into the blending machine. Opening of the collector / bin (for collecting / dropping the cut threads upon opening the gunny bags) should be at a height of 580 mm from the standing surface (on working platform). This will help the 5^{th} p, 50^{th} p and 95^{th} p workers to drop the cut threads into the bin without much bending. Space requirement for a standing person should encompass 95^{th} percentile arm span while minimum dimension for whole body access through an aperture in a wall surface is 780 mm × 500 mm while wearing heavy clothing (Pheasant and Haslegrave, 2006). Therefore, the working platform was designed (1840 mm × 820 mm) considering the 95th p Indian male arm span of 1829 mm, winter clothing and dimensional similarity requirements with lifting platform and the worktable. A small standing platform (required only for 5^{th} p male) should be at a height of 133 mm from ground level. The small standing platform surface should be 500 mm × 500 mm considering foot length and sideways step length of 5^{th} p adult Indian male.

4.13.1.2 Proposed design of granulator workstation along with its components

The length of the rod used by the worker to lift the defective product (chair) was observed to be 1180 mm while railing height from working platform base and railing diameter was found to be 700 mm and 10 mm respectively. Absence of toe board on the working platform was also noticed. It was observed that the recommendations proposed in various literature sources were not adhered in the working platform design of the existing granulator workstation. Bureau of Indian Standards (BIS) (Bureau of Indian Standards IS, 1992a) recommends that all staging and scaffoldings or platforms must be properly anchored, secured and placed firmly with railings at least 900 mm high. Toe-boards of 100 mm in height should also necessarily be provided to prevent accidental falling of persons (Bureau of Indian Standards, 1992a). Tool boxes must be made available to decrease the chances of falling of tools and also the sides of the platforms must be provided with toe boards to prevent falling of tools and loose materials (Bureau of Indian Standards, 1992b). Space requirement for a standing person should encompass 95^{th} percentile arm span and from literature sources, the minimum dimension for whole body access through an aperture in a wall surface is to be 780 mm x 500 mm while wearing heavy clothing (Pheasant and Haslegrave, 2006). Maximal handle contact area which minimizes surface stress on the skin occurs on handles 50 to 60 mm in diameter (Pheasant and Haslegrave, 2006). The above mentioned design recommendations pertaining to the immediate working area were suitably modified in the CAD model of the granulator workstation (figure 4.8) for further evaluations on a virtual platform.

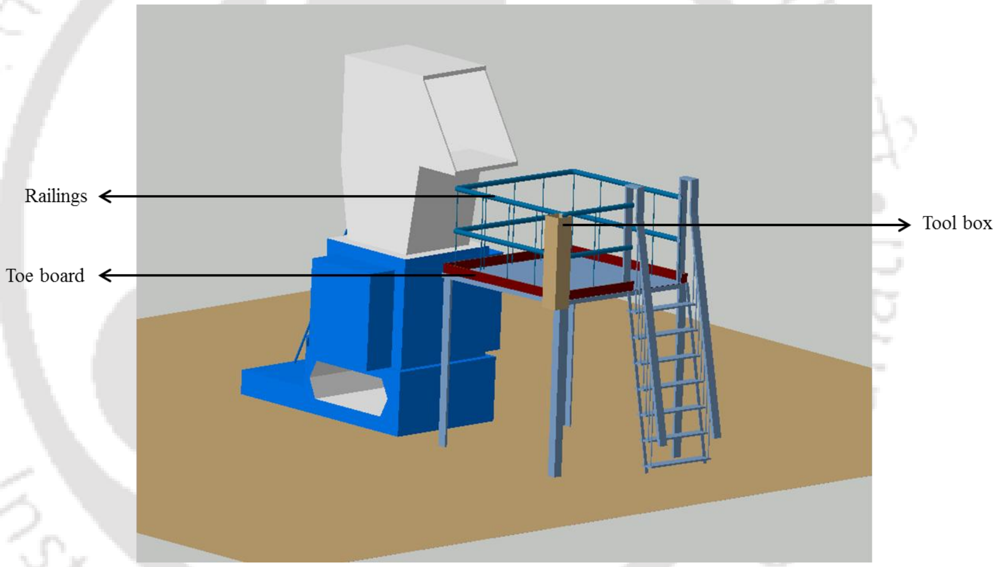


Figure 4.8 Proposed granulator workstation design

4.13.1.3 Proposed design of injection-molding workstation along with its components

The geometric design of equipment and work places should be based on anthropometry of user population in order to ensure man-machine compatibility (Bureau of Indian Standards, 1991a). Initial concept models were interfaced with 5^{th} p, 50^{th} p and 95^{th} p digital human models representing adult Indian male anthropometry. Practical low-cost improvements, validated with application of basic ergonomics principles in workstation design should be attempted in the context of small workplaces in industrially developing countries (Kogi, 2012). Hence, workstation accessories which can be easily built and low in cost were conceptualized (figure 4.9) initially for assessments.

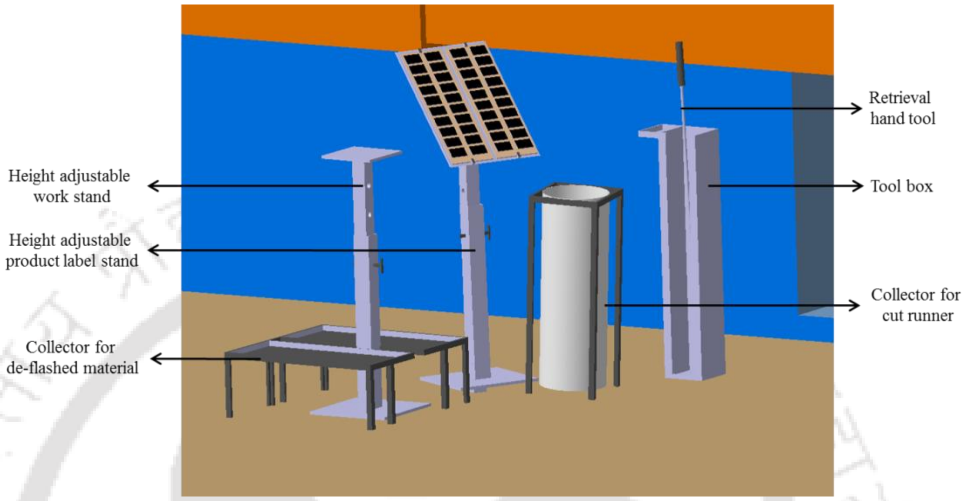


Figure 4.9 Proposed injection-molding workstation design

4.13.2 Interfacing proposed workstation models with digital human models

The extreme groups in a population encompassing smallest and largest body dimensions are represented by 5th percentile female and 95th percentile male respectively. However if the workforce is dominated by a particular gender, then it is appropriate to design for the predominant gender (Helander, 1995). Hence, the proposed shop-floor workstations and the associated work methods were assessed using 5th p, 50th p and 95th p male digital human models corresponding to the Indian adult male body dimensions.

4.13.3 Observations - Visualization of body segments in comfortable and uncomfortable range of motion

4.13.3.1 Blending workstation

The proposed blending workstation model was interfaced with 5th p (figure 4.10), 50th p (figure 4.11) and 95th p (figure 4.12) digital human models towards evaluations of various work activities.

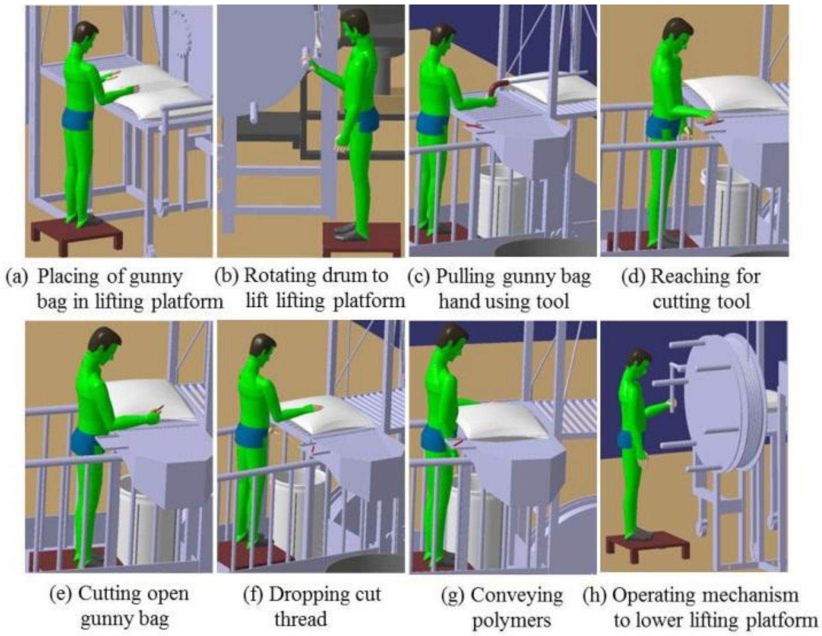


Figure 4.10 Virtual representations of working postures for 5th p male in the proposed blending workstation model

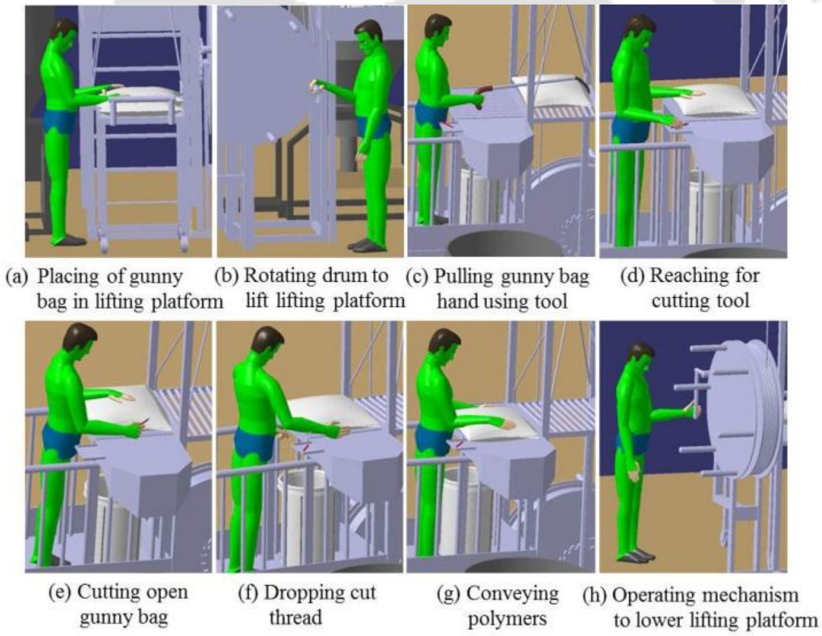


Figure 4.11 Virtual representations of working postures for 50th p male in the proposed blending workstation model

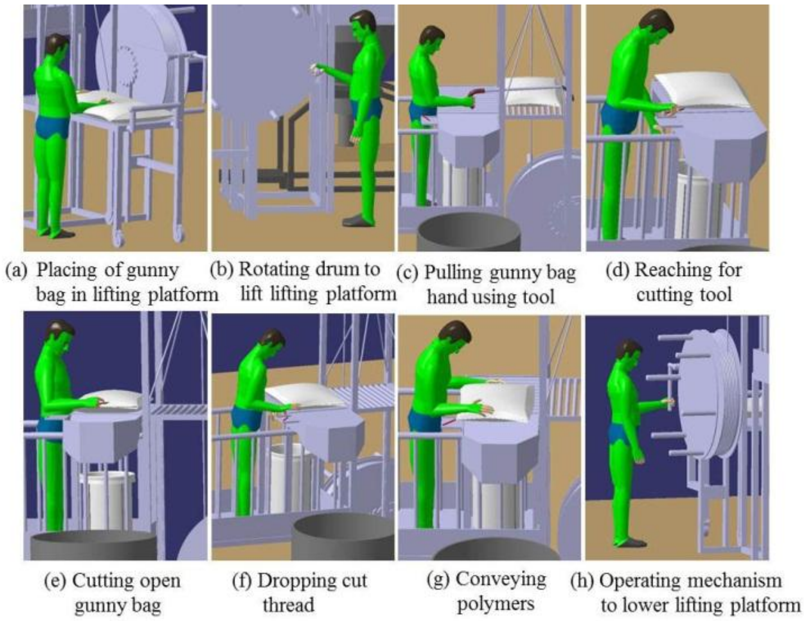


Figure 4.12 Virtual representations of working postures for 95th p male in the proposed blending workstation model

4.13.3.2 Granulator workstation

The proposed granulator workstation model was interfaced with 5th p (figure 4.13), 50th p (figure 4.14) and 95th p (figure 4.15) digital human models towards evaluations of various work activities.

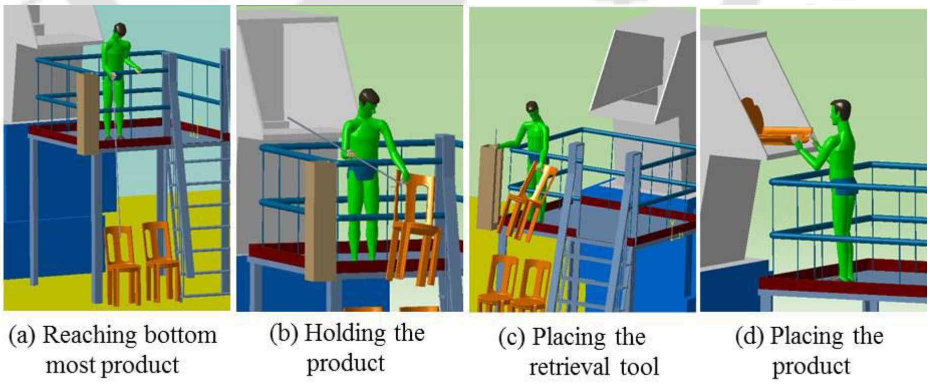


Figure 4.13 Virtual representations of working postures for 5th p male in the proposed granulator workstation model

(a) Reaching bottom most product (b) Holding the product (c) Placing the retrieval tool (d) Placing the product

Figure 4.14 Virtual representations of working postures for 50th p male in the proposed granulator workstation model

(a) Reaching bottom most product (b) Holding the product (c) Placing the retrieval tool (d) Placing the product

Figure 4.15 Virtual representations of working postures for 95th p male in the proposed granulator workstation model

4.13.3.3 Injection-molding workstation

Proposed injection-molding workstation accessories was interfaced with 5th (figure 4.16), 50th (figure 4.17) and 95th p (figure 4.18) digital human models towards evaluations of various work activities.

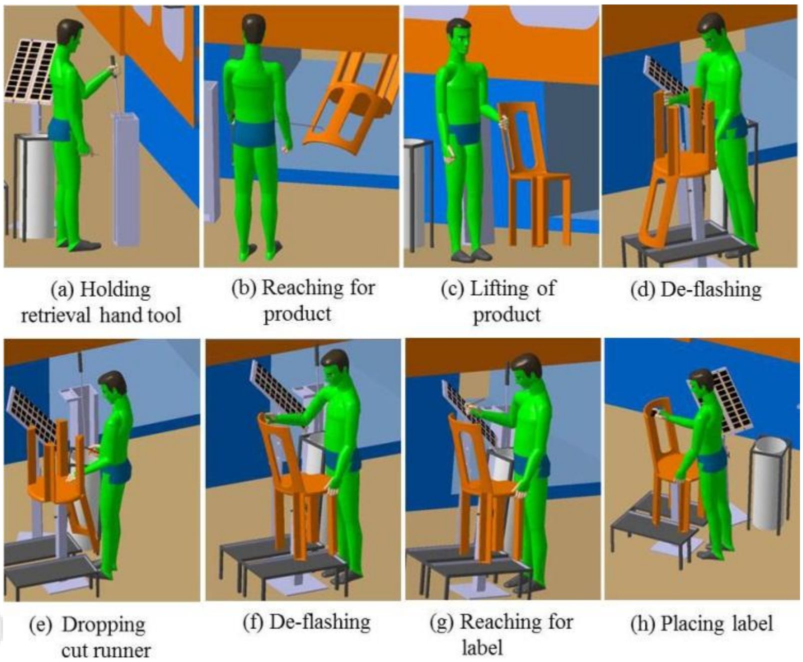


Figure 4.16 Virtual representations of working postures for 5th p male in the proposed injection-molding workstation model

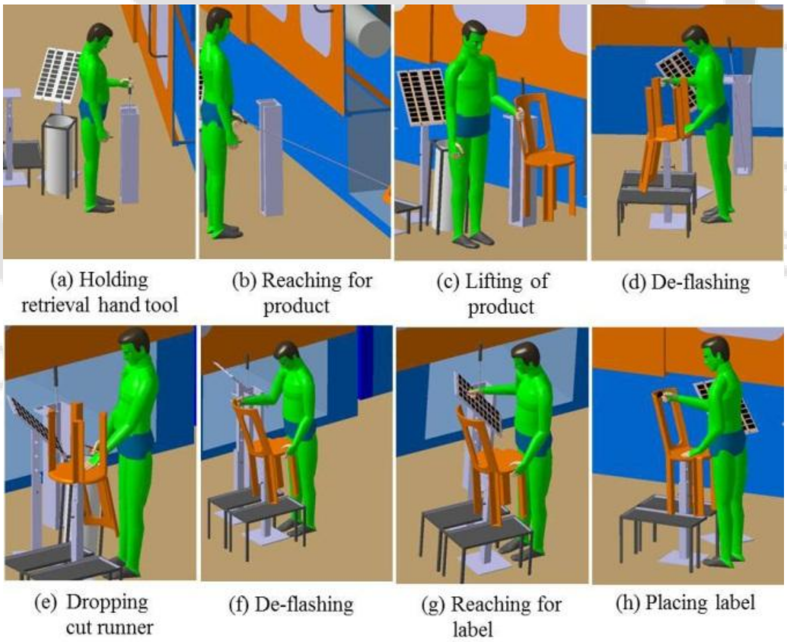


Figure 4.17 Virtual representations of working postures for 50th p male in the proposed injection-molding workstation model

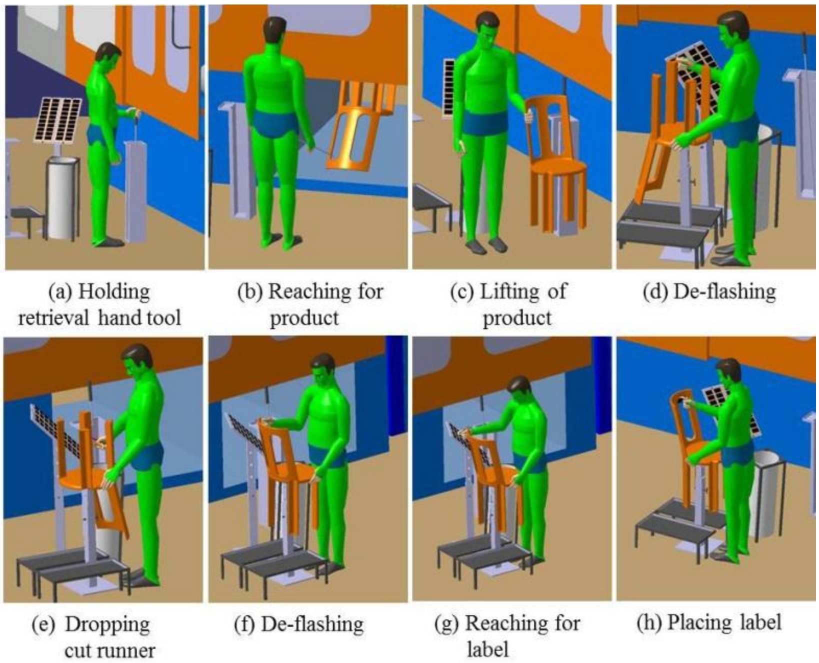


Figure 4.18 Virtual representations of working postures for 95th p male in the proposed injection-molding workstation model

4.13.4 OWAS, REBA scores and spinal load analysis

4.13.4.1 Blending workstation

The OWAS and REBA scores (table 4.14) were calculated from the respective body segment angles as visualized in digital human modeling software for postures shown in figures 4.10, 4.11 and 4.12. The spinal load analysis was performed using the digital human modeling software for the postures are shown in figures 4.10, 4.11 and 4.12.

Table 4.14

OWAS, REBA and spinal load analysis for working postures in the proposed blending workstation

Digital Human Models	Posture	OWAS	REBA Rt:Lt	L4 - L5 Spine Limits (Newton)	
				Compression	Joint shear
5th p (fig. 4.10)	a	1	2:2	389 - 2099	27 - 122
	b	1	2:1		
	c to h	1	1:1		
50th p (fig. 4.11)	a	1	2:2	888 - 3350	75 - 266
	b	1	2:1		
	c to h	1	1:1		
95th p (fig. 4.12)	a	1	2:2	575 - 3204	28 - 248
	b	1	2:1		
	c to h	1	1:1		

Legends: Rt - Right body side; Lt - Left body side

4.13.4.2 Granulator workstation

The OWAS and REBA scores (table 4.15) were calculated from respective body segment angles as visualized in digital human modeling software for postures shown in figures 4.13, 4.14 and 4.15. The spinal load analysis was performed using the digital human modeling software for the postures are shown in figures 4.13, 4.14 and 4.15.

Table 4.15

OWAS, REBA and spinal load analysis for working postures in the proposed granulator workstation

Digital Human Models (male)	Posture code	OWAS Action Category	REBA (Rt) Score	REBA (Lt) Score	L4 - L5 Spine Limits (Newton) Compression	Joint shear
5^{th} p (fig. 4.13)	a	1	2	2	862 - 1450	10 - 61
	b	1	3	4		
	c	1	3	3		
	d	1	1	1		
50^{th} p (fig. 4.14)	a	1	2	2	1167 - 2274	11 - 73
	b	1	3	3		
	c	1	3	3		
	d	1	1	1		
95^{th} p (fig. 4.15)	a	1	2	2	1091 - 1992	9 - 92
	b	1	1	1		
	c	1	1	1		
	d	1	1	1		

Legends: Rt - Right body side; Lt - Left body side

4.13.4.3 Injection-molding Workstation

OWAS and REBA scores for working postures (figures 4.16, 4.17 and 4.18) in proposed workstation for 5^{th} p, 50^{th} p and 95^{th} p male digital human models are shown in table 4.16.

Table 4.16

OWAS, REBA and spinal load analysis for working postures in the proposed injection-molding workstation

Digital Human Models	Posture	OWAS Action category	REBA (Rt) Score	REBA (Lt) Score	L4 - L5 Spine Limits (Newton) Compression	L4 - L5 Spine Limits (Newton) Joint shear
5th p (fig. 4.16)	a	1	1	2	369 – 695	7 - 34
	b	1	3	3		
	c	1	1	1		
	d	1	2	2		
	e	1	3	3		
	f	1	1	1		
	g	1	3	3		
	h	1	2	2		
50th p (fig. 4.17)	a	1	1	1	659 – 1718	7 - 55
	b	1	1	1		
	c	1	1	1		
	d	1	2	2		
	e	1	3	3		
	f	1	2	1		
	g	1	3	3		
	h	1	1	1		
95th p (fig. 4.18)	a	1	1	1	453 – 972	11 - 45
	b	1	1	1		
	c	1	1	1		
	d	1	1	1		
	e	1	1	1		
	f	1	1	1		
	g	1	3	3		
	h	1	1	1		

Legends: Rt - Right body side; Lt - Left body side

4.13.5 Operation chart of the expected work activities in the proposed workstations

4.13.5.1 Blending workstation

The left and right hand operation chart for understanding the work elements in a work cycle likely to be encountered in the proposed blending workstation is given in table 4.17.

Table 4.17

Operation chart for work elements in a work cycle visualized in the proposed blending workstation

Left hand	Symbol	Symbol	Right hand
Reach for gunny bag in material handling trolley	o	o	Reach for gunny bag in material handling trolley
Grip gunny bag	O	O	Grip gunny bag
Convey gunny bag to lifting platform by sliding / pushing movement	o	o	Convey gunny bag to lifting platform by sliding / pushing movement
Release grip on gunny bag	O	O	Release grip on gunny bag
--	--	o	Reach for rotating drum handle
--	--	O	Grasp for rotating drum handle
--	--	o	Rotate drum to lift lifting platform
Reach for rotating drum handle	o	--	--
Grasp for rotating drum handle	O	O	Release grip on rotating drum handle
Rotate drum to lift lifting platform	o	--	--
Release grip on rotating drum handle	O	--	--
--	--	o	Reach for retrieval tool on work table
--	--	O	Grasp retrieval tool
--	--	o	Transport retrieval tool
--	--	O	Position retrieval tool
--	--	o	Pull / slide gunny bag from lifting platform to work table
--	--	o	Transport retrieval tool
--	--	O	Place retrieval tool on work table
--	--	O	Release grip on retrieval tool
Reach gunny bag	o	o	Reach gunny bag
Grasp gunny bag	O	O	Grasp gunny bag
Position gunny bag for conveying polymer into blending machine	O	O	Position gunny bag for conveying polymer into blending machine
--	--	O	Release gunny bag
--	--	o	Reach for cutting tool in tool holder
--	--	O	Grasp cutting tool in tool holder
--	--	o	Transport cutting tool
--	--	O	Position cutting tool for cutting open gunny bag
Grasp cut thread	O	O	Cut open gunny bag
Carry cut thread	o	O	Grasp cutting tool
Drop cut thread in bin	O	--	--
Reach for gunny bag	o	o	Transport cutting tool to tool holder
Grasp gunny bag	O	O	Release cutting tool in tool holder
--	--	o	Reach for gunny bag
--	--	O	Grasp gunny bag
Pull / slide gunny bag	o	o	Pull / slide gunny bag
Convey polymers into blending machine	o	o	Convey polymers into blending machine
Release grip on gunny bag	O	O	Release grip on gunny bag
Reach for ratchet and pawl handle	o	--	--
Grasp handle	O	--	--
Operate ratchet and pawl mechanism to bring down lifting platform	o	--	--
Release grip on ratchet and pawl handle	O	--	--

Legends: o – transportation (moving hand to grasp the article); O – actions (grasping, positioning, using or releasing the article) (adopted from Barnes, 1980)

4.13.5.2 Granulator workstation

The left and right hand operation chart for work elements in a work cycle estimated in the proposed granulator workstation is shown in table 4.18.

Table 4.18

Operation chart for work elements in a work cycle visualized in the proposed granulator workstation

Left hand	symbol	symbol	Right hand
Reach for railing	o	O	Reach for retrieval hand tool in tool box
Grasp railing	O	O	Grasp tool
--	--	O	Lift retrieval hand tool from tool box
--	--	O	Reach for chair with retrieval hand tool
--	--	O	Position retrieval hand tool on chair
--	--	O	Lift chair
Release grip on railing	O	--	--
Reach for chair	o	--	--
Grasp chair	O	--	--
--	--	O	Release retrieval hand tool from chair
--	--	O	Transport retrieval hand tool to tool box
--	--	O	Position retrieval hand tool on tool box
--	--	O	Release retrieval hand tool
--	--	O	Reach for chair
--	--	O	Grasp chair
Transport chair towards grinding slot	o	O	Transport chair towards grinding slot
Position chair on grinding slot	o	O	Position chair on grinding slot
Lift chair for final push into grinding machine	o	O	Lift chair for final push into grinding machine
Push chair into grinding machine	o	O	Push chair into grinding machine

Legends: o – transportation (moving hand to grasp the article); O – actions (grasping, positioning, using or releasing the article) (adopted from Barnes, 1980)

4.13.5.3 Injection-molding workstation

The left and right hand operation chart for work elements in a work cycle likely to be encountered in the proposed injection-molding workstation is shown in table 4.19.

Table 4.19

Operation chart for work elements in a work cycle visualized in the proposed injection-molding workstation

Left hand	symbol	symbol	Right hand
--		o	Reach for de-flashing hand tool
--	--	O	Grasp de-flashing hand tool
--	--	o	Reach for retrieval tool
--	--	O	Grasp retrieval tool
--	--	O	Transport retrieval tool
--	--	O	Position retrieval tool
--	--	O	Retrieve finished product
Reach for finished product	o	--	--
Grasp finished product	O	O	Transport retrieval tool
--	--	O	Place retrieval tool
--	--	O	Release grasp on retrieval tool
Transport finished product to work stand	O	--	--
Position finished product on work table	O	o	Reach for finished product
Grasp finished product	O	O	Position cutting tool on finished product
--	--	O	De-flash finished product
--	--	O	Grasp cut runner
--	--	o	Reach for dropping runner
--	--	O	Release cut runner into collector
--	--	o	Reach for finished product
--	--	O	Grasp finished product
Invert and position finished product	O	O	Invert and position finished product
position finished product on work stand	O	O	position finished product work stand
Grasp finished product	O	O	Position cutting tool on finished product
--	--	O	De-flash finished product
--	--	o	Reach for product label 1
--	--	O	Remove product label 1
--	--	o	Reach for finished product
--	--	O	Stick product label 1
--	--	o	Reach for product label 2
--	--	O	Remove product label 2
--	--	o	Reach for finished product
--	--	O	Stick product label 2
--	--	O	Grasp finished product
Remove finished product form work stand	O	O	Remove finished product form work stand

Legends: o – transportation (moving hand to grasp the article) ; O – actions (grasping, positioning, using or releasing the article) (adopted from Barnes, 1980)

4.13.6 Work Measurement

4.13.6.1 Blending workstation

It was observed that the work elements in a typical work cycle were not performed in the same sequence consistently by operators in the blending workstation. Sometimes, the operators were noticed taking rest pauses after keeping gunny bags on the working platform before conveying it into the blending machine. Time aspects of work elements with irregular cycles (irregular work pattern) is beyond the capacity of any observer to observe and record without external aids like video graph (Mundel & Danner, 1994). Blending activities are not immensely affected by time considerations and constraints when compared with the main production processes involving injection-molding machines. There was no psychosocial risk pertaining to tempo (work pace). Temporal demand did not appear to be a risk factor during subjective workload assessment. Hence the study of time aspects concerning work activities towards work measurement in the blending workstation was not considered.

4.13.6.2 Granulator workstation

It was observed that the work elements in a typical work cycle were not performed in same sequence consistently by the operators in the granulator workstations. Sometimes operators were noticed taking rest pauses, keeping the retrieved parts (from stack) on machine slot or on working platform before conveying it into the granulator. Recording time aspects of work elements with irregular cycles (irregular work pattern) is beyond the capacity of any observer to observe and record without external aids like video graph (Mundel and Danner, 1994). Hence study of time aspects (work measurement) was not feasible as continuous videography was not permitted by the factory managements. Granulator is auxiliary equipment not immensely affecting the time considerations and constraints of the main production process / output using the injection-molding machines. The finished goods which are identified to be defective during the injection-molding process are stacked and kept in designated storage areas. They are then brought and placed near the granulator workstation to be grinded as required. There was no psychosocial risk pertaining to tempo (work pace). Temporal demand did not appear to be a risk factor during subjective workload assessment. Hence study of time aspects concerning work activities towards work measurement in granulator workstation was not considered.

4.13.6.3 Injection-molding workstation

Work activities in the injection-molding workstations were performed in the same sequence consistently by the operators. Time aspects are very important in performing / completing the work elements in a work cycle (retrieving the finished product, de-flashing the finished product etc.) in the injection-molding workstations. The time aspects of work elements in the injection-molding workstations were recorded by direct observation as videography was not permitted by the factory managements. The injection-molding machine cycle time observations (table 4.20) and observed operator work cycle times (table 4.21) before and after design modifications and comparisons are tabulated as shown below.

Table 4.20

Injection-molding machine cycle times

Factory	Descriptive statistics				Inferential statistics[1]	Inferential statistics[2]		
	Existing workstation		Proposed workstation		Existing Vs. proposed workstation	Factory	Existing workstation	Proposed workstation
	Mean	SD	Mean	SD				
A	54.8	0.7	54.9	0.7	NS	A vs. B	*	*
B	51.6	0.6	51.6	0.5	NS	A vs. C	*	*
C	52.1	0.6	52.2	0.5	NS	B vs. C	*	*

Legends: 'NS' – No Significant difference ($p > 0.05$); '*' - Significant difference ($p < 0.05$); 1 Wilcoxon signed rank test;
2 Mann-Whitney U test

Table 4.21

Observed operator work cycle times in injection-molding workstations

Factory	Operator	Descriptive statistics				Inferential statistics[1]	Inferential statistics[2]		
		Existing workstation		Proposed workstation		Existing Vs. Proposed workstation	Operator	Existing workstation	Proposed workstation
		Mean	SD	Mean	SD				
A	A	46.6	3.2	44.4	2.4	NS	A vs. B	*	NS
	B	42.9	2.1	41.7	1.8	NS			
B	A	37.5	3.1	34.5	1.5	NS	A vs. B	*	NS
	B	35.9	1.9	34.4	1.3	NS			
C	A	31.6	2.3	30.9	1.6	NS	A vs. B	*	NS
	B	32.9	3.2	31.4	2.2	*			

Legends: 'NS' – No Significant difference ($p > 0.05$); '*' - Significant difference ($p < 0.05$); 1 Wilcoxon signed rank test;

2 Mann-Whitney U test

4.14 Discussion

4.14.1 Blending workstation

In the proposed design, initially the gunny bag is to be placed onto the lifting platform after transferring from the material handling trolley by sliding action (figure 4.10, a); followed by rotating the drum (coupled to a pulley mechanism, figure 4.7) to lift the lifting platform along with a gunny bag kept on it (figure 4.10, b). Rotation of the drum is to be stopped when the lifting platform reaches an appropriate height matching with the work table. Ratchet and pawl mechanism had to be introduced as a safety device in order to prevent the backward rotation of drum. After climbing onto the working platform, the worker may slide the gunny bag with the help of a hand tool (figure 4.10, c) over the worktable. Cutting tool is taken from tool holder (figure 4.10, d) and gunny bag is cut open (figure 4.10, e). The cut thread is dropped into a collector / bin kept below (figure 4.10, f). Finally, the polymers inside the gunny bags are conveyed (figure 4.10, g) into the blending machine. After conveying the polymers, the worker has to climb down from the platform and release the ratchet and pawl mechanism in order to bring down lifting platform (figure 4.10, h). A small standing platform was required for the 5th p male (figure 4.10) towards maintaining a proper height relationship with the equipment and the task. Proposed design enabled the work activities to be performed without the need for platform for the 50th and 95th p male digital human models (figure 4.11, figure 4.12). A detailed step by step visual representation of the anticipated work activities in the proposed workstation is shown (figure 4.19) for easy understanding.

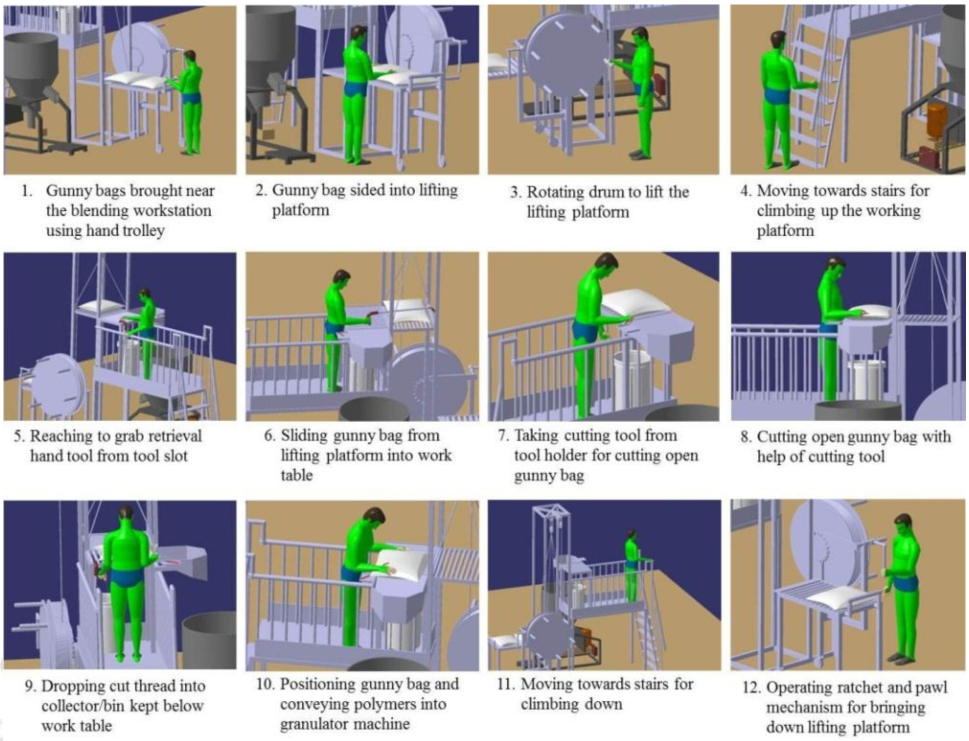


Figure 4.19 Virtual representations of anticipated work activities in the proposed blending workstation

It has been observed that in the proposed workstation model, majority of the working postures has been categorized as negligible risk and a few under low risk category (table 4.14). Since lifting of gunny bags was removed (replaced by sliding movements) as a result of workstation and work method design modifications in the proposed model, compressive and shear forces acting on lumbar segments were within the safe recommended limits. It was observed in the proposed workstation model that all the work activities were performed near about the elbow joint level and body segments were fairly approximated to neutral positions as recommended by (Pheasant and Haslegrave, 2006). Comfortable working postures are achieved as visualized by green color on the digital human models for all working postures (figure 4.10, 4.11 and 4.12).

The operation chart (table 4.17) indicated increased work activities in the proposed workstation, when compared with activities in the existing workstation (table 4.2). However, work activities may be performed in a safe and comfortable manner when compared with the existing workstation. Since work activities in the blending workstation involved lifting weights (gunny bags) against gravitational force, design of a concept workstation without being aided by power driven devices (motor driven) featuring minimum / reduced work activities is a challenging task.

4.14.2 Granulator workstation

After preliminary investigations it was observed that working postures ‘a’, ‘b’ (figure 4.2 and 4.5) (reaching for top most products (chair) in the stack and retrieving it using operator’s hand) should be avoided. Postures ‘a’, ‘b’ (figure 4.2 and 4.5) contributed to a high risk level on the right side of the body while imposing medium risk on the left body side as per REBA analysis. OWAS analysis recommends corrective action to be taken in near future. This is due to presence of many body segments in uncomfortable angular range of motion, unacceptable body balance (figure 4.5) as well as relatively high (but within safe limits) (Leyland, 2008) L4-L5 spine joint compression when compared to other working postures (table 4.3). Hence, working method represented by working postures ‘a’ and ‘b’ (figure 4.2 and 4.5) are recommended to be avoided at all costs and therefore, not taken up for further investigations in subsequent evaluations. It is recommended that pushing and pulling actions are generally performed most easily between shoulder height and elbow height or a little below (Pheasant and Haslegrave 2006). The worker lifts the product well above shoulder level (posture ‘h’; figure 4.2 and 4.5) in order to convey it into grinding slot after initially placing the product in the respective machine slot (as seen from working posture ‘g’; figure 4.2 and 4.5). REBA analysis indicated low risk (change may be needed) and medium risk (investigate further and change soon) for left and right body side respectively, while OWAS analysis recommended corrective action to be taken in near future. Thus, the working method as found in posture ‘h’ (figure 4.2 and 4.5) is not recommended and should be changed. After some deliberations in this direction, it was suggested that the worker should place the product (chair) in an opposite (inverted) manner as shown in figure 4.13 (posture ‘d’) and lift it minimally for conveying it into the machine slot. Hence, the working postures g and h (figure 4.2 and 4.5) were combined into one single working posture represented by posture d (figure 4.13, 4.15 and 4.16). This work method enabled to convey the product (chair) into the granulator machine at a position well below the shoulder height for all the manikins (5^{th} p, 50^{th} p and 95^{th} p) under study. It should also be understood that for enabling the worker to perform the operation below elbow height, platform height should be raised (from ground level) considerably. In doing so, the operation of lifting the chair will be affected significantly as it will necessitate the operator to work in uncomfortable position to lift chairs in bottom ranges of the stack, which is not practically feasible. As it is evident, if all manikins considered for the study (Indian adult male of 5^{th}, 50^{th} and 95^{th} percentile body dimensions) are able to lift bottom most chair in the stack adopting comfortable working posture then lifting chairs from middle position in stack will not pose a problem. Hence, working posture 'c' (figure 4.2 and 4.5) (lifting the product from mid position in the stack) was not taken into consideration for further evaluations.

In the next step four postures (figure 4.13, 4.15 and 4.16) designated as 'a' (locating and retrieving of bottom most product from ground), 'b' (holding the product towards the end of lift), 'c' (holding product and placing the lifting tool) and 'd' (lifting and positioning product for delivery into granulator) were taken into consideration for further evaluations. The working postures 'b' and 'c' (figure 4.13, 4.15 and 4.16) corresponded to postures 'e' and 'f' (figure 4.2 and 4.5). Posture 'd' (figure 4.13, 4.15 and 4.16), in principle, characterized combination of the working postures 'g' and 'h' (figure 4.2 and 4.5) but principally posture 'h' (figure 4.2 and 4.5). Postures mentioned 'a', 'b', 'c' and 'd' (figure 4.13, 4.15 and 4.16) were rendered and evaluated after modifying the design of working platform as recommended (figure 4.8).

The main design parameters found to be influencing the working postures are increase of the railing height to 900 mm, provision of toe board to a height of 100 mm from the standing base of working platform, and provision tool holder respectively as seen in (figure 4.8). Length of lifting rod should be approximately 2030 mm to facilitate comfortable working posture (without any postural risks and within safe biomechanical limits) for locating and retrieving bottom most products from the stack for all manikins (5^{th} p, 50^{th} p and 95^{th} p). Lifting rod of smaller length may be provided to facilitate easy and comfortable lifting of chairs from top positions of stack without compromising on working postural comfort. Postural analysis using REBA along with OWAS for postures named 'a', 'b', 'c', and 'd' is shown in table 4.15. All working postures ('a', 'b', 'c' and 'd'; figure 4.13, 4.15 and 4.16) were categorized as negligible and low risk for both body sides as per REBA analysis. OWAS analysis suggested that no further change is required. It should be understood that such a scenario was made possible due to presence of joints near about neutral position of their range of movement (indicated by presence of green color on 5th p, 50th p and 95th p manikin's body surface during assessments). Postural comfort is found to be greatest in the resting position or when joints are in midpoint of allowable range of movement whereas extreme postural discomfort is experienced at extreme position of joint rotation (Corlett and Clark, 1995). MacLeod (2000) also recommended working in neutral postures as it helped in optimal position of each joint thereby providing strength, control over movements and least physical stress on the joint and surrounding tissue. MacLeod (2000) advocated that the neutral position is near the midpoint of full range of motions and at this position the muscles surrounding a joint are equally balanced.

The L4-L5 spine compression and joint shear data (obtained from digital human modeling software) were well within safe recommended limits for postures 'a', 'b', 'c' and 'd' (figure 4.13, 4.15 and 4.16) as shown in table 4.15. The biomechanical stresses are found to be reduced considerably when compared with working postures before workstation design and work method modifications and are within safe recommended limits. A good posture is the one which minimizes biomechanical stresses on body (Chaffin and Anderson, 1991) and should be kept within safe limits when the work involved material handling (Capodaglio et al., 1997).

Provision of tool holder attached to the working platform (within reach of 5th, 50th and 95th p male manikins) paved way for eliminating the work activity of changing the tool orientation (to place tool on working platform railing) which is normally performed two times (towards the end of upward retrieval motion and at beginning of downward movement to locate and retrieve the chair) within a single work cycle. Workstation / work cell redesign and changes in the operator movements can improve the job being performed from an ergonomics perspective (Black, 2007) as seen in the present research work. The proposed operation chart after workstation design modifications with inclusion of tool holder was recorded as shown in table 4.15.

The existing granulator equipment was installed and commissioned after purchasing it from the original equipment manufacturer. Other existing work accessories namely, working platform and retrieval hand tool were custom designed and installed by workers themselves with the help of factory management without considering basic the ergonomic design principles. The main reasons for the prevalence of risky working postures were due to lack of proper awareness regarding laws of work and design guidelines proposed by national and international organizations / researchers. This scenario has led to prevalence of physical mismatch between worker's anthropometry, biomechanics and overall workstation design as well as associated work methods. As overall workplace design and work methods were found to be inadequate from an ergonomic design perspective, investigations and subsequent modifications were very much needed in the granulator workstation. Ergonomic interventions results in better working conditions and promote job satisfaction in conventional production lines (Wong and Richardson, 2010). Production operators should be directly involved in the ergonomic design of systems used by them (Drury, 2000) while continuous effort should be taken by production system designers to identify and develop strategies for improving the application of ergonomics and productivity of system (Neumannr et al., 2002). Design modifications were made in the CAD model of the granulator workstation in accordance with recommended guidelines. Subsequent evaluations were performed virtually using digital human modeling software. Digital human modeling software was helpful in aiding examinations in a realistic manner without the necessity of building costly real physical mockups and trials involving actual humans. Analysis of postures in a detailed manner for workplace design is simplified with help of computer aided techniques using digital human models (Carey and Gallwey, 2002). Investigations in real life situations match with the digital human modeling simulations (Fritzsche, 2010). Designers can demonstrate the usability of the final design of a product with the help of a representation of a real human in a virtual environment using digital human modeling (Kuo and Wang, 2012) as also seen in present study. Digital human modeling approach has the capability to visualize and evaluate concept models from physical ergonomics design perspective in the shop-floor of MSMEs in the manufacturing sector in a very effective and easy manner.

4.14.3 Injection-molding workstation

After further discussions with production supervisors / managers and injection-molding operators, some minor modifications were made in the designs (figure 4.20). Tool stand was made visually appealing. Collector for the runner was designed to easily fix the collecting bag. Collector for gathering de-flashed material was designed to hold more amount of de-flashed material.

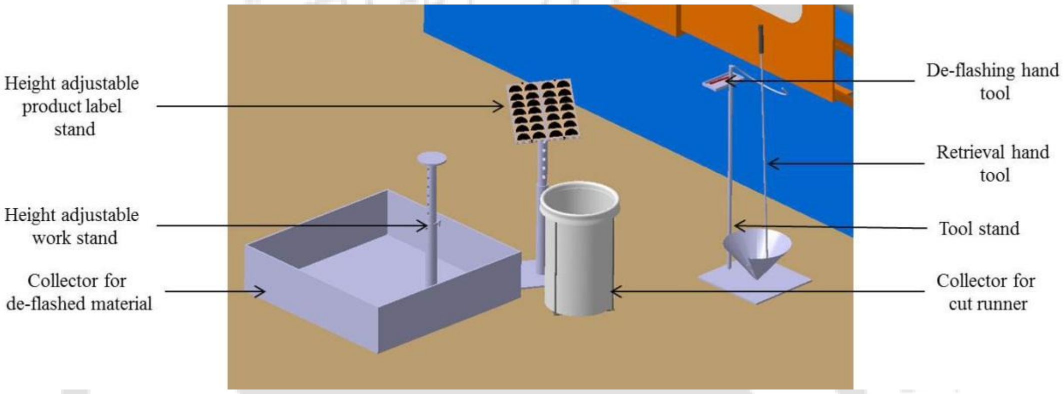


Figure 4.20 Final proposed model of the injection-molding workstation fixture

The dimensions of collector was 1000 mm × 1000 mm × 250 mm with one side open for allowing de-flashed materials to fall into it. Opening of collector for dropping cut runner should be 600 mm from ground level considering height of gunny bags used and also for facilitating 5th p, 50th p and 95th p males to drop cut runners without much back bending. Height of adjustable work stand top surface from ground level should be 631 mm for 5th p, 809 mm for 50th p and 832 mm for 95th p while height of adjustable product label stand from ground level should be 995 mm for 5th p, 1046 mm for 50th p and 973 mm for 95th p. Such adjustments in height will help different percentile workers to work in good, less risky work postures using same workstation fixtures. Length of the retrieval hand tool is 1100 mm and it helped 5th p, 50th p and 95th p DHM to retrieve the finished product (from under the injection-molding machine) without back bending. De-flashing hand tool holder may be provided at a height of 900 mm on the tool stand and other dimensions of tool stand may be suitably appropriated accordingly.

The proposed workstation model enabled 5th p, 50th p and 95th p digital human models to perform work activities with body segments within comfortable range of motion as visualized by presence of green color in body segments. Further, all working postures were categorized as negligible risk and also under low risk category (table 4.16). Spinal load analysis using digital human modeling software indicated that compressive and shear forces (L4-L5 segment) generated for working postures were within safe limits for 5th p, 50th p, and 95th p digital human models for all work postures (table 4.16).

Work activities in the existing and proposed workstation were charted using the operation chart. The number of work activities was marginally less in the proposed workstation when compared with the existing workstation (table 4.19). Workers will definitely be benefitted by minor reduction in work activities because of large number of work cycles are repeated every day. The operation chart may vary based on hand orientation (right / left) and tool holding preferences of individual workers.

The conventional method for determining number of cycles to be timed using stopwatch (for timing individual operator work cycle time) adopting direct time study (intensive sampling) procedure was followed. Measurement of actual time required to complete a task may be done by stop watch or any other timing device (Mantena et al., 2008). Three factories were included in the time study investigations for ease of comparisons. Two operators from each factory who were experienced having necessary skill and knowledge were selected and the observed operator cycle time was noted as per the recommendations given in table 4.1. The present research work is primarily focused on design interventions for minimizing the awkward working posture. Setting of the standard times for a particular work activity is not the objective of present study. Hence individual work element (reaching for finished product, de-flashing finished product and reaching for product label etc.) were combined and the entire operation of retrieval of an individual finished product and subsequent activities were taken as a single work task for recording the time. In other words time was observed for completing a particular work cycle instead for individual work elements.

The typical injection-molding machine cycle consists of transferring the blended polymer granules from the feed hopper into a heated barrel (where polymers are melted), injecting melted material (with help of a plunger mechanism) into a clamped shut mold and the final ejection of the finished product after a predetermined cooling period (Morris, 2013). The injection-molding machine cycle time for a similar product (armless chair, figure 4.3) was observed from three different factories. The observed operator work cycle times (time taken for processing individual finished products) were timed for two individual workers per factory engaged in processing similar products (armless chair). Sixty injection-molding machine cycle times and observed operator work cycle times were considered in present study as per the recommendations given by Bureau of Indian Standards (1995). Statistical analysis for comparison of injection-molding machine cycle times (between factories), observed operator work cycle time (before and after the design modifications) between workers (within factory and between factories) was performed using SPSS v.20.0 (IBM, USA) software.

The physical mockup of the final proposed model was constructed for trials with different factory workers (figure 4.21 and 4.22) for elucidating feedback as well as for conducting work studies. The proposed workstation model was well received by workers and appreciated by production supervisors / managers.

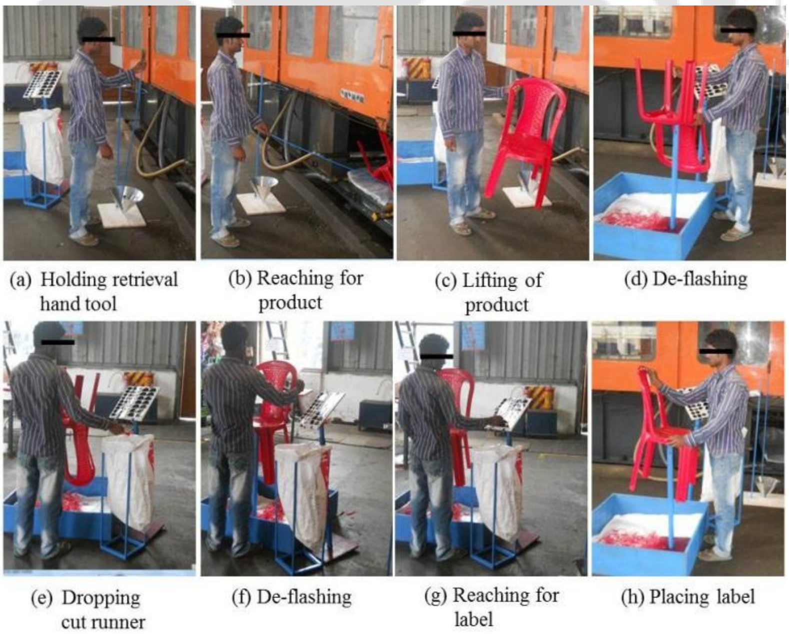
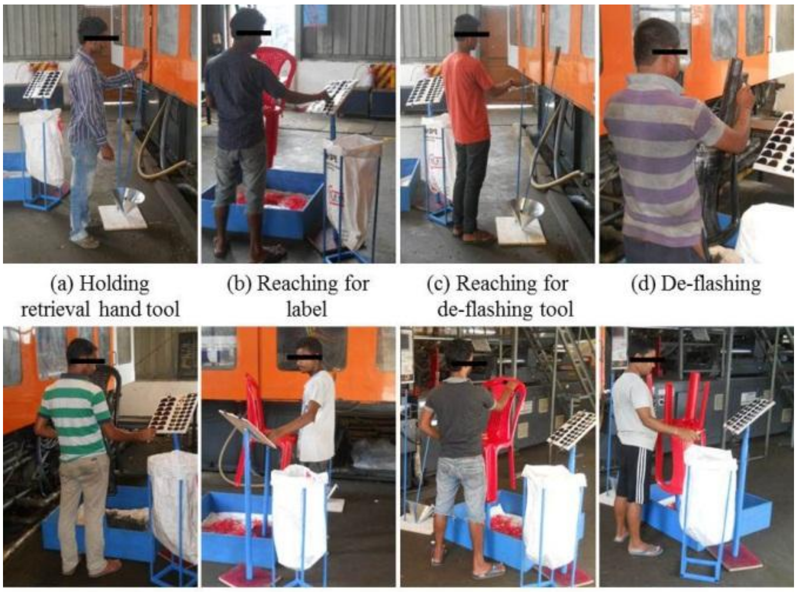


Figure 4.21 Trials by individual worker with proposed model of injection-molding workstation fixtures



(a) Holding retrieval hand tool; (b) Reaching for label; (c) Reaching for de-flashing tool; (d) De-flashing; (e) Reaching for label; (f) Reaching for label; (g) Placing label; (h) Dropping cut runner

Figure 4.22 Trials by different workers in proposed model of the injection-molding workstation fixtures

The injection-molding machine cycle time significantly varies (table 4.20) from factory to factory in spite of similar products manufactured. Variation in the injection-molding machine cycle time depends on the type of polymers (virgin, recycled) used, quality of finished product, quality of mold and cooling rate of the mold. The injection-molding machine cycle time determines the time available for workers towards processing the finished product (retrieval of finished product, de-flashing activities and sticking product label). Work measurement is also used for comparative purposes (Subramanian and Mital, 2008). Significant difference in observed operator work cycle times were observed between two (skilled and experienced) operators within factory (table 4.21) while processing similar finished products even though no significant differences in injection-molded machine cycle times were observed (table 4.20) within factory. Reduction in observed operator work cycle times was noticed when operators used modified / re-designed workstation models, but reduction in observed operator cycle times were not significant (table 4.21). However, since large number of products are manufactured every day, workers / operators are expected to be benefitted immensely due to reduced work cycle time. Further in modified / re-designed workstation setup, observed operator work cycle times between operators within individual factories were not significantly different from each other (table 4.21). No significant difference in injection-molding cycle times was noticed (during timing of the observed operator work cycle times) before and after workstation design modifications (table 4.20) in the respective factories.

Since the proposed workstation fixture design consisted of individual modules, the entire setup can be positioned as per desire of the worker and also based on working hand (right / left) (figure 4.23).

Figure 4.23 Different positional arrangements of proposed model of the injection-molding workstation fixtures

4.15 Conclusion

The workers in the existing shop-floor workstations (blending, granulator and injection-molding) were working in awkward work postures and also experienced occurrence of body parts discomfort. It was recognized that non-conformance of workstation designs and work methods to recommended guidelines led to the incidence of awkward working postures. The percentage of shop-floor workstation workers suffering from discomfort during work was significantly higher, when compared with the people working in other occupations, even though they were similar in age, weight, standing height and work experience. Research outcome (**fulfilling objective - 4 of the research work**) towards modification of work method and redesigning of workstation considering demographic constraints enabled significant downgrading the risk perception of operational postures. **Hence the hypothesis - H_2 of the research work is established.**

The innovative combination of research methods featuring questionnaire study, postural assessment tools, statistical analysis, digital human modeling and simulation, and work study technique is perhaps first of its kind for investigations in Micro, Small and Medium Enterprises (MSMEs) in India. The research methodology in present research work may be adopted by production engineers / managers / supervisors in manufacturing sector of MSMEs in IDCs like India towards identifying physical risk factors and developing validated context specific design solutions for humanizing work.

Chapter V

Indoor physical work environment: An ergonomics perspective

Abstract

Work in the contemporary era is predominantly performed indoors. The indoor physical environmental factors (air movement, temperature, relative humidity, illumination, noise level, etc.) affect the performance of humans. Generally due considerations are not given to physical environmental aspects while designing individual workstation / workplace / facilities in any organization / industry. Keeping this scenario in mind it was felt that ample information in a consolidated form pertaining to basic indoor environmental parameters will definitely help in identifying and proposing guidelines for humanizing work environment. Present chapter strives to collect, segregate and arrange needed information to represent an appropriate knowledge body. Good indoor environment is beneficial in terms of increasing productivity, satisfaction and overall well-being of people. Variations in specifications proposed by different organizations / bodies and other studies were observed. Standards proposed should be used as a basis, while due attention should be given to ethnic and geographic diversity, individual differences and adaptability while designing / planning any indoor workplace / workstation / facility.

5.1 Introduction

In the present era most of the work is performed indoors. It is reported that people spend about 90% of their time indoors in industrialized countries (Höppe, 2002; Yu et al., 2009). This trend is increasingly seen in developing countries also. Organizations like ISO (International Standards Organization), CEN (European Committee for Standardization), ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers), IES (Illuminating Engineering Services) and OSHA (Occupational Safety and Health Administration) put forth standards and accepted methods for evaluation of physical environments while periodically revising existing standards and publishing new ones. Developing countries have their own national bodies to formulate or adopt standards for regulating indoor environment. Objective of the Bureau of Indian Standards (the founder member of ISO) is to provide harmonious development of standardization, marking, quality certification and evolving a national strategy for according recognition to standards and formulation of Indian Standards (Bureau of Indian Standards, 2012).

Ergonomic design of work place / environmental ergonomics / ergonomics of physical environment refer to the creation of ambient conditions that are appropriate, acceptable and does not compromise on work performance or worker's health (Hedge, 2005). Acceptability and performance of the occupants are affected by various factors such as light, noise, air quality and thermal environment (Olesen, 1995). Standards will not ascertain workplace design, but has the ability to give a useful starting point for successful design (Parsons, 1995). With the above thought in mind, an attempt has been made to compile all need based information regarding basic indoor environmental variables like air movement, temperature, relative humidity, illumination and noise level. The work described in chapter V is expected to be helpful subsequently (chapter VI and chapter VII) for investigating indoor occupational environment and recommending proposals for redesign of small and medium scale injection-molded plastic furniture manufacturing shop-floor.

The main indoor physical environmental parameters relate to air movement, temperature, relative humidity, illumination and noise level. The following paragraphs elucidate the importance of these factors, investigating techniques and the proposed recommendations.

5.2 Indoor thermal environment

Among different indoor environmental conditions / factors, thermal comfort is preferred and given greater importance (Höppe, 1988) compared to visual, acoustic and air quality. Humans have the capability for adapting to hot environments due to the presence of sweat glands in their skin. Various thermo regulatory mechanisms are at work in the human body for maintaining heat balance. Individual characteristics of the worker, thermal environment and the requirements of the task are some of the factors which influence the ability to work in heat. Productivity and contentment of the occupants can be increased as a result of improved thermal comfort (Höppe, 1988) and the occupant's control over the environment (Bauman et al., 1995).

Thermal comfort is the state of mind that expresses satisfaction with the thermal environment and is assessed by subjective assessment (ANSI/ASHRAEStandard55, 2010). The ASHRAE thermal sensation seven point scale ascertains the sensation of warmth / cool that a person experiences whereas Bedford seven point thermal comfort scale estimates the state of thermal comfort experienced by the subject in a given environment (Deb and Ramachandraiah, 2010). Surveys using the ASHRAE and BEDFORD scales **(Appendix X)** can be administered in real buildings or laboratories (climate chambers) and subsequently 'comfort vote' of subjects is considered to determine a particular temperature (the comfort temperature) or combinations of conditions they find most comfortable (Nicol and Pagliano, 2007). Based on experience, it is found that although two scales are semantically different, subjects use these two scales in a similar way (Nicol and Pagliano, 2007). Studies reveal that the desired sensation on the ASHRAE scale depends not only on outdoor temperature but also on indoor temperature prevailing at the particular moment (Humphreys and Hancock, 2007). The occupants of an indoor space will feel neither warm nor cold when asked about thermal state and preference if they are thermally comfortable (Frontczak and Wargocki, 2011).

From observations in British factories, the following recommendations were suggested (Belbin, 1970 a). The optimum air temperature recommended for persons doing light work is 18.3˚C and comfort zone is between 15.6˚ C to 20˚C. The respective values for individuals engaged in sedentary office work and active factory jobs are 19.4˚C to 22.8 ˚C and 12.8˚C to 15.6 ˚C respectively. The optimum mean radiant temperature (globe temperature readings) recommended for light work is 18.3˚C and the comfort range is between 16.7˚C to 20˚C. Maximum relative humidity recommended is 70% and the ideal level of air movement is around 150 mm/sec. In a study conducted in South Africa, both male and female participants from all major ethnic groups were tested in a mobile climate laboratory. Environmental conditions likely to be encountered in South African factories were simulated. The best performance for many tasks was observed when air temperature was 32 ˚C (the temperature being in the range of 20 ˚C to 38 ˚C) and relative humidity 25 % although subjects preferred temperatures were between 20 ˚C to 23 ˚C (Meeser et al., 1982).

ISO 9241 has mentioned 20˚C - 24 ˚C for winter and 23˚C - 26˚C for the summer as the acceptable indoor temperature range for workers (Bridger, 2002). Further satisfactory ranges for humidity are 60 - 80% for 20 ˚C, 50 - 70% for 22˚C, 45 - 65 % for 24˚C and 40 - 60 % at 26 ˚C; while temperatures ranging between 19 ˚C and 23˚C with 40% - 70% relative humidity were found to be acceptable by majority of the workers (Bridger, 2002). The acceptable range of temperature is between 20.9 ˚C and 30.4 ˚C when mean daily outdoor temperatures ranged from 25.1 ˚C to 28.8 ˚C, relative humidity ranged from 40% to 65%, (with an average of 51%) and air velocity between 0.02 m/s to 0.42 m/s (Huang et al., 2012). ISO thermal comfort standards are believed to be valid, reliable and usable for practical application; but it is specified that variations could occur due to ethnic, geographic diversity, individual differences, varied prior thermal experiences and adaptability (Olesen and Parsons, 2002). Field studies by many researchers using subjects in tropical settings indicated that people find certain physical environments comfortable which differ from the recommendations made in ISO 7730, especially for buildings which are free running. As a result, it is understood that ISO 7730 underestimates the range of temperatures which people find comfortable (Nicol, 2004; Peeters et al., 2009). The PMV-PPD (Predicted Mean Vote- Predicted Percentage of Dissatisfied) model for thermal comfort included in ISO 7730, is based on steady state energy balance of the human body and interviews conducted in controlled climatic conditions which envisages thermal sensation and comfort satisfaction of human body as a function of six parameters related to the indoor environment (internal temperature, air velocity, humidity, mean radiant temperature) and to the occupants (activity and clothing) without any relationship with external environmental conditions (Sicurella et al., 2012). Moreover, the PMV-PPD model does not consider the transient conditions prevalent in naturally ventilated buildings and the variation in the occupant's activity and behavior (Sicurella et al., 2012). It was also observed that ergonomic standards concerning the physical environment has been proposed taking technical or engineering approach, while little importance given for human responses and ergonomic methods (Parsons, 1995).

One of the most controversial issues in the applied research area of thermal comfort is the contention between the 'static' model which is based on steady state laboratory experiments (ASHRAE's Standard 55 Thermal Environmental Conditions for Human Occupancy and the ISO Standard 7730) and field study based on the 'adaptive' model (de Dear et al., 1997). In the last decade thrust is given towards extensive studies in adaptive thermal comfort. From various literature resources it was observed that that adaptation (behavioral, physiological and psychological) of people are based on their experiences, season, climate, semantics, habituation (building design and building function), genetic factors, acclimatization and adjustment (personal, technological and environmental), demographics (gender, age and economic status), social conditioning and cognition (attitude, preference and expectations) (Peeters et al., 2009; de Dear et al., 1997). There is a big argument whether standards based on laboratory experiments are applicable to buildings which are free running (not air conditioned at all) and also its universal applicability (all types of buildings, climates and populations) ignoring the importance of contextual influences that can undermine peoples' responses to a given set of thermal conditions (Brager and de Dear, 1998).

Following are some of the insights reported in a literature survey conducted by Frontczak and Wargocki, (2011).

- Women and men differed in their ratings on thermal conditions.
- Variations regarding nature of the indoor environment (workplace / home / public / private), its characteristics, duration of occupancy, and level of education, the relationship with superiors and colleagues and time pressure were reflected in the ratings given by the respondents.
- The color of light influenced the thermal comfort rating very lightly and room decoration had no impact on the rating.
- Neutral and comfort indoor temperatures increased with increasing outdoor temperatures in naturally ventilated buildings.

Thermal comfort is a state of mind and judgment of comfort is a cognitive process influenced by physical, physiological, psychological and other factors like mood, culture, individual, organizational and social factors (Djongyang et al., 2010). From reviewing literature, Djongyang et al. (2010) have mentioned that International comfort standards given by ASHRAE and the ISO are based on theoretical analyses of human heat exchange performed in mid-latitude climatic regions in North America and Northern Europe, and that these standards are suitable for static and uniform thermal conditions; based on the hypothesis that regardless of race, age and gender, human beings feel comfortable in a narrow and well-defined range of thermal conditions. Comfort surveys indicated that factory workers acclimatized to warm humid tropical climatic conditions can tolerate up to 30˚C which can go up to 34˚C if the air velocity is 0.6 m/s while performing light manufacturing activities without much ventilation (Wijewardane and Jayasinghe, 2008). People can be comfortable at temperatures up to or even exceeding 30 ˚C especially if they are using a fan based on results from many field studies in hot climates (Nicol, 2004). It was observed in a survey that neutral temperature was 31.93 ˚C showing the occupant's high tolerance and adaptability, and it was also found that their perception of thermal comfort varied on account of spatial conditions / visualizations (Deb and Ramachandraiah, 2012). The range of comfort temperature varied in different climatic zones and also during the different months of the year as found during a study in North East India with respect to vernacular buildings (Singh et al., 2010 b). The responses indicated by people to thermal environments in naturally ventilated buildings in hot humid zones of China revealed a close relationship between indoor physical variables and occupants' clothing insulation with outdoor climate (Zhang et al., 2010). From a literature review based on field evidence of thermal adaptation in built environment, it is reported that a distinction exists between thermal comfort responses in air-conditioned vs. naturally ventilated buildings due to a combination of past thermal history in buildings and differences in levels of perceived control (Brager and de Dear, 1998). In the case of free running buildings, the outdoor environment has a bearing on indoor environmental conditions (Nicol and Pagliano, 2007; Nicol, 2004; Ahmed, 2003; Peeters et al., 2009; Sicurella et al., 2012). Many researchers have found that the temperature at which the occupants find comfortable (Bedford scale) or neutral (ASHRAE scale) is linearly related to the monthly mean of outdoor temperature (Nicol and Pagliano, 2007).

Air temperature, radiant temperature, air humidity and rate of air movement are considered to be the factors deciding whether a person will feel hot, cold or comfortable (Belbin, 1970 a). Air temperature, humidity, air velocity, mean radiant temperature, clothing level and metabolic rate are primary factors affecting thermal comfort (Atmaca et al., 2007). Dry-Bulb Temperature (DBT), Wet-Bulb Temperature (WBT), Relative Humidity (RH), Globe Temperature (GT) and air movement are the parameters involved in the measurement of thermal environment (Bridger, 2002). Operative temperature (the average of air temperature and radiation temperature) can also be investigated by means of measurement (Isaksson and Karlsson, 2006). WBT is measured with the help of a wet-bulb thermometer while GT is measured traditionally with the help of mercury in the glass thermometer positioned in a metal sphere painted matt black (Bridger, 2002). Modern heat stress monitors use thermistors (electrical transducers) which can measure DBT, WBT, GT and air movement (Bridger, 2002). PMV and PPD indices meter is also available which can measure air temperature, Mean Radiant Temperature (MRT), airflow velocity and relative humidity (Huang et al., 2012). Measurements scheduled to cover the entire range of outdoor mean daily temperatures during the year and all the measurements taken at a distance of 1.45 m from the floor level was the methodology adopted in a field study at a large underground car park (Chow et al., 1996). When the subjects were filling the survey sheet, Deb and Ramachandraiah, (2012) spontaneously measured indoor environmental parameters (including air temperature) at a height of 1 m from ground level in a study involving assessment of thermal comfort of people who were in a seated posture. Three heights of measurements (0.1 m, 0.6 m and 1.2 m) above floor level are specified in ISO and ASHRAE standards (Brager and de Dear, 1998).

Following information should be taken into consideration while designing facilities for indoor thermal comfort (Bridger, 2002).

- Ventilation is necessary to make available fresh air and remove accumulated noxious gases and contaminants.
- Ventilation removes heat generated in the working area by convection and helps in cooling the human body.
- At low temperatures, air speeds less than 0.1 m/s tend to cause a sensation of staleness and stuffiness.
- Air speeds greater than 0.2 m/s may be perceived as draughty.
- Air speeds of 0.2 m/s to 0.5 m/s will help in the body cooling in hotter conditions, especially when relative humidity is high.
- Working areas can be cooled by ventilating buildings at night utilizing the cool outside air.

The average temperature (during the summer in an automotive part manufacturing factory) decreased by about 3.6˚C with improvement in thermal comfort as a result of installing the axial fan ventilating system (Lee et al., 2005). It is significant to note in this context that the natural ventilating system capable of controlling summer temperatures can provide adequate ventilation to control the level of odors and carbon dioxide production (Fordham, 2000). However, it is also highlighted that ventilation rates required to control summer temperatures are very much higher than the ventilation rates required to control pollution or odors (Fordham, 2000).

5.3 Relative humidity

The most prevalent measure for humidity of indoor ambient air is the relative humidity (Nicol, 2004). The recommended range of relative humidity is between 30% and 70% for indoors. Lower values tend to have negative effects on mucous membranes of the upper respiratory tract leading to dryness which in turn cause them to lose their protective function against infections whereas higher relative humidity levels cause condensation, moistening at the cool external walls and formation of mold (Höppe, 1988). The ASHRAE Standard 62-2001 recommends the relative humidity of 30% - 60% in an office environment and the general humidity sensation varies with exposure time (Tsutsumi et al., 2007). Humidity has been investigated in a number of field surveys in hot climates and was found to have a significant effect on comfort temperature (Nicol, 2004). But further research is still needed as the size of its effect is generally small; relative humidity being a relative value is mainly dependent on air temperatures and the fact that water vapor pressure being a more robust measure is not always recorded (Nicol, 2004).

5.4 Indoor illumination

Illumination at the work place also plays a very important role in improving the efficiency, safety and health of workers. Workplace illumination is among the important parameters influencing the worker's productivity in terms of speed, the quality of work, downtime, absenteeism and accident rates (Hoffmann et al., 2008). There exists a strong relationship between illumination and task completion times (Bennet et al., 1997). Recommendations regarding lighting of building interiors with respect to illumination levels required to perform visual tasks at acceptable standards are published by Illuminating Engineering Society (IES). Photometry is known as the science dealing with the measurement of light. The amount of light falling on a surface is termed as illuminance and the unit used for measurement is known as lux. Light meter / luxmeter is used for measuring illuminance. The history of lighting recommendations suggested by experts is in fact, very, interesting. During the early period of last century illuminance recommended was about 30 lux to 100 lux while by the middle of the century (in 1940s) it was increased between 300 and 500 lux, and by 1972 illuminance recommended for office work in the U.S. was fixed between 500 lux and 2000 lux (Rea and Boyce, 2005). In the later quarter of the century recommended illuminance was similar to those recommended during the 1940s, but it should be understood that expert opinions reflect the context in which they are suggested (Rea and Boyce, 2005). Light intensities in the range of 300 lux - 1000 lux are necessary for manual work and it was observed that lighting by the ceiling mounted neon lights often caused headache, eye strain and fatigue (Höppe, 1988). The acceptable level of illumination was above 300 lux as found out in a field study in offices when the illumination intensity in the survey ranged from 93 lux to 1424 lux (Huang et al., 2012). A study spanning 16 months reported a significant increase in productivity levels of workers who were provided with the controllable task lighting arrangement (Juslén et al., 2007). It is intriguing to know that installing new lighting systems may improve the performance of people on account of its impact on visual performance, visual comfort, the visual ambience and interpersonal relationships (Juslén and Tenner, 2005). Visual tasks in assembly and inspection tasks like rough work, medium work, fine work and very fine work require 200, 400, 900 and 2000 lux respectively (Belbin, 1970 b). The recommendations given by the Bureau of Indian Standards (BIS) for lighting are found in the following standards. Code of practice for day lighting of the factory for different types of industrial buildings and process is given in IS: 6060:1971, Reaffirmed 2004 (Bureau of Indian Standards, 1972). Code of practice considering the interior illumination for the various types of working interiors / activity can be found in IS: 3646 (Part I): 1992, Reaffirmed 2003 (Bureau of Indian Standards, 1992 c). IES recommended higher illumination levels than the European guidelines which indicate the difference of opinions among experts. This is evident from the fact that German DIN prescribes 1000 lux for precise assembly works while IES recommends 3000 lux for the same (Helander, 1995).

5.5 Noise levels

Noise has a negative impact on the working efficiency, harms the hearing faculty and annoys the people who are exposed to it (Belbin, 1970 c). The units used to measure the frequency and intensity of sound is known as hertz (Hz) and decibel (dB) respectively. Measurements can be made using sound level meters (as prescribed by International Electrotechnical Corporation) (Bureau of Indian Standards, 2005 a), noise spectrum meter (Huang et al., 2012), noise dosimeter (instrument worn by the worker) and octave noise analyzer (capability to read output noise levels in dBA and availability of different weighting built in filters). Sound level meters have three types of weighting the sound which are known as A, B and C scales of which dBA scale (or weighting function) is widely used in industries (Helander, 1995). In the United States of America, it has been regulated to limit noise exposure to 90 dBA for an 8 hour period while in Greece it is suggested that 80 dBA exposure dose is harmless while 85 / 90 dBA is termed as a guide number, but the reliability of these exposure limits is debated among the scientific fraternity (Eleftheriou, 2002). ISO specifies the maximum acceptable noise dosage of 85-90 dBA with a maximum exposure time of 8 hours / day and 5 days / week (40 hours / week) (Habali et al., 1989; Shaikh, 1999). As most of the industrial plants in developing countries work 8 hours / day and 6 days / week which amount to 48 hours / week, it was suggested that a limit be kept at 88 dBA (claimed to be consistent with ISO specifications) for steady noise (Shaikh, 1999). The accepted level of noise was found to be below 49.6 dB in a controlled field study (to assess the relationship between the satisfaction level of acoustic environment and A-weighted sound pressure level) in offices when the noise level in the investigations ranged from 44.3 dB to 65.4 dB (Huang et al., 2009).

In India IS 15575 (Part 1): 2005 (superseding IS 9779:1981) which is identical with International Electro technical Commission (IEC 61672-1 (2002)) gives specifications for electro acoustical performance specifications for three different kinds of sound level meters (Bureau of Indian Standards, 2005a). The three sound level meters are a conventional sound level meter that measures exponential time-weighted sound level, the integrating-averaging sound level meter that measures time-average sound level and integrating sound level meter that measures sound exposure level. The methods of measurement of noise emitted by machines are addressed by

IS: 4758-1968 (Reaffirmed 2002) which follows the recommendations made by ISO (495) dealing with the general requirements for preparation of test codes for measuring noise emitted by machines (Bureau of Indian Standards, 1968).

5.6 Discussion and Conclusion

A lot of effort has been made to formulate environmental standards for increasing productivity, performance, satisfaction and the overall well-being of the people working indoors. Standards pertaining to measuring instruments and measurement techniques backed by scientific validation have helped in according universal conformity in instrumentation and measuring practice. But there exists a remarkable variation in the recommendations made by organizations, individual studies and during different time periods. It is apparent that these variations are due to contextual influences, individual preferences, gender difference and adaptability of human beings, influence of subjective assessments, geographic and other factors associated with the subjects / human volunteers involved in investigations. Therefore, apprehensions are expressed regarding the universal adoptability of recommended standards. Worker / employees are exposed to physical demands and work environment associated with the job(s). This presents a strong case for taking the worker into confidence during ergonomic evaluations, especially in the industrial sector. This approach is labeled participatory ergonomics and its benefits have been well established (Day, 1998).

Standards proposed should be used as a basis, while due attention should be given to ethnic and geographic diversity, individual differences and adaptability while designing / planning any indoor workplace / workstation / facility. The need of the hour is location / country specific contextual investigations / research into indoor physical environmental factors. This will ultimately result in formulation of standards / recommendations which are industry / location / user (targeted people) specific in nature. Governments across the nations should encourage research in this direction. Results obtained should be used for giving birth to national as well as local data bases. Such data bases will be of immense help to engineers / designers / ergonomists / supervisors / managers / occupational health care professionals for designing or modifying facilities / layouts at any location. Any new industry / facility in any particular locality should be encouraged to adopt such recommendations and subsequently monitored through suitable enforcement initiatives. Thus, the overall system design optimization for human well-being to make them compatible considering their needs, abilities and limitations being the goal of Ergonomics / Human Factors can be realized on a global scale due to the development of contextual location specific recommendations / standards and its subsequent application with respect to indoor environmental factors. Working population is sure to be benefitted by such initiatives. The good indoor environment is beneficial in terms of increasing productivity, satisfaction and overall well-being of people.

Chapter VI

Indoor occupational environment investigations in the shop-floor of injection-molded plastic furniture manufacturing factories of North East India

Abstract

The indoor work environment parameters like air movement, temperature, relative humidity, illumination and noise level play a significant role in maintaining the workers well-being besides ensuring good working conditions. Investigations pertaining to the indoor work environment from an occupational health perspective in plastic processing industries are scarcely reported from the industrially developing countries like India. Present chapter aims to investigate the important indoor work environmental parameters prevailing in shop floor workstations. Comparisons of prevailing conditions with guidelines specified by scientific organizations and researchers indicate the need for implementing context specific corrective actions. Research methodology used in the present study may be easily adopted for identification of season and location specific indoor work environment risk factors in the industrial workstations. Context specific suggestions are also proposed for improving the indoor work environment.

6.1 Introduction

The indoor work environment (air movement, temperature, relative humidity, illumination and noise level) significantly influences the interaction between people and their immediate work environment. Investigations pertaining to indoor work environment from an occupational health perspective in plastic processing industries are scarcely reported from industrially developing countries like India. Indian plastic processing industries have promising growth potential, capabilities for a huge employment generation, but are highly fragmented consisting mainly of Micro, Small and Medium Enterprises (MSMEs) (Central Institute of Plastics Engineering and Technology, 2010) . Studies incorporating on one or more environment variables have been reported in industrial units like ceramics (Parikh et al., 1978), cotton gins (Arude, 2007), carpet (Wani and Jaiswal, 2012), coal mining (Dey et al., 2006), glass bangle (Rathod et al., 1987; Rastogi et al., 1989), garment / textile (Bedi, 2006; Talukdar, 2001), glass (Srivastava et al., 2010), aluminium casting (Biswas et al., 2012), automobile; leather; glass; textiles; fertilizer; and electricity (power) generation (Balakrishnan et al., 2010), automotive parts manufacturing (Ayyappan et al., 2009), sheet metal (Sen et al., 2010), forging (Singh et al., 2009 a), oil mill

(Kumar et al., 2008), jute mill (Ganguli and Rao, 1954), cricket bat manufacturing (Wani and Jaiswal, 2011) and zarda manufacture (Ghosh and Barman, 2007) from India. Occupational health risk factors pertaining to the indoor work environment are prevalent across various sectors in India. Petro chemical projects in India are tremendously increasing plastic processing activities employing huge human resources (Assam Industrial Corporation Limited, 2010; Haldia Petrochemical Industries Limited, 2014). Foreseeing tremendous scope for enhanced plastic processing activities in India, it is the right time to investigate the prevailing indoor work environmental parameters (air movement, temperature, relative humidity, illumination and noise level) in workstations of small and medium scale injection-molded plastic furniture manufacturing shop-floor. Comparisons of prevailing conditions with guidelines specified by scientific organizations and researchers indicate the need for implementing context specific corrective actions. Research methodology used in the present study may be easily adopted for identification of season and location specific indoor work environment risk factors in industrial workstations. Context specific suggestions are also proposed for improving indoor work environment.

6.2 Methodology

6.2.1 Selection of factories and workstations for investigations

Seven injection-molded plastic furniture manufacturing factories (under the small and medium sector) in the state of Assam, India were identified. Authors of the present paper were permitted by four company managements (located at 26.1833° N latitude and 91.6667° E longitude) for conducting investigations. The non-disclosure agreement regarding identification of these factories compels to keep them anonymous. Manufacturing processes typically comprises of blending (mixing), granulator (grinding / scrap grinder) and injection-molding workstations. Hence these workstations were selected for gathering necessary information.

6.2.2 Measurement of indoor work environment parameters

Satisfactory results / conclusions are achieved when indoor environmental conditions are measured throughout the year (Huang et al., 2007). Hence, factories were visited in a random manner, once every week from January to December during year 2013. Data relating to the environmental variables were obtained during the general working shift as permission for data collection was granted from 9 a.m. to 5 p.m. Readings were collected at three different times of the day (10 a.m., 1 p.m. and 4.45 p.m.) during factory visits on the last working day (Saturday) of every week for all seasons.

Thermal conditions were measured at a height of 1.2 meters (Brager and de Dear, 1998) from the workers standing surface. The Globe thermometer was exposed at least 25 minutes before the reading was noted as recommended by OSHA (1999). WBGT (Wet Bulb Globe Temperature) index for indoors was calculated using the formula, WBGT (in) = 0.7 Wet Bulb Temperature (WBT) + 0.3 Globe Temperature (GT) (Helander, 1995; Bridger, 2002). Hand held pocket weather meter was utilized to record the prevailing thermal conditions. Illumination was measured (in accordance with the task, working plane and point of operation) using light / lux meter (Chengalur et al., 2004; Padmini and Venmathi, 2012). Noise (A-weighted sound level) was measured (within the worker's hearing zone) using sound level meter in the worker's working position / workstations (occupational health practitioners are concerned with noise in workplaces / occupied places instead of its originating source) as workers were working in fixed work places (Singh et al., 2009 a; Bridger, 2002; Chengalur et al., 2004; Bureau of Indian Standards, 1968; OSHA, 2013 a).

The questionnaire **(Appendix XI)** used in a thermal comfort evaluation study (Deb and Ramachandraiah, 2010) was adapted for assessing the worker's perception of thermal environment and comfort. ASHRAE thermal sensation scale (comfort band within -1 and +1), which has been widely used in comfort research (Deb and Ramachandraiah, 2010; Indraganti, 2010; Mishra and Ramgopal, 2014) was used for evaluating the thermal sensation (warm and cool) experienced by the workers. Bedford scale (satisfactory range -1 to + 1) which estimates the thermal comfort (Deb and Ramachandraiah, 2010; Mishra and Ramgopal, 2014) was also used in the present study. Acceptance of thermal environment at various locations (Deb and Ramachandraiah, 2010) was evaluated by assessing overall acceptance votes. Responses were collected from workers / operators present during the factory visits for recording of indoor environmental data. Responses were collected based on overall thermal sensation and the thermal comfort of the worker for the whole week. The use of supplementary lights, fan, personal protective devices and clothing behavior of workers (for contextual understanding of the prevailing practices) were also recorded during the factory visits.

6.2.3 Analysis of collected data

Assam state is characterized by a tropical climate with semi - dry summer and cold winter, rainfall ranging between 1500 mm to 2600 mm, average humidity of 75%, the maximum and minimum temperature of 38.5 ºC and 7 ºC respectively (NIC, 2013). Climate of Assam is categorized into four distinct seasons, namely pre monsoon (March - May), monsoon (June - September), post monsoon (October - November) and winter (December – February) (RKMP, 2011). Recorded data was grouped under four climatic seasons (Pre monsoon, monsoon, post monsoon and winter). Comparison of observations for identifying season specific risks (Deb and Ramachandraiah, 2010; Wani and Jaiswal, 2011; Wani and Jaiswal, 2012) and location specific risks (Biswas et al., 2012) was performed. Data pertaining to the measured indoor environmental variables did not follow normal distribution. Hence Kruskal-Wallis nonparametric ANOVA test (using SPSS v.20.0 (IBM, USA) software was used to check the existence of significant difference in mean values (at $p < 0.05$ significance level) between observations of individual indoor environmental parameters (average air movement, DBT, RH, GT, WBGT index, illumination and noise levels) at each workstation in different climatic seasons.

6.3 Results

6.3.1 Indoor physical work environment in the shop-floor workstations

Mean values (along with standard deviation) of indoor work environment parameters measured at different shop-floor workstations and categorized under different climatic seasons are tabulated as shown in table 6.1.

Table 6.1

Indoor physical work environment in the shop-floor workstations

Work-stations	Season	AWS (m/s)	DBT (ºC)	GT (ºC)	WBGT (index)	RH (%)	Illuminance (lux)	Noise (dBA)
Blending	Pre monsoon	0	30.8 ± 2.7	30.8 ± 3.1	25.8 ± 2.2	58.2 ± 20.1	88.9 ± 73.3	81.9 ± 5.3
	Monsoon	0	32.3 ± 2.5	33 ± 2.8	29.5 ± 2.7	72.1 ± 11.7	140.1 ± 125.2	84.2 ± 5.3
	Post monsoon	0	28.1 ± 2.5	28.5 ± 2.4	25.1 ± 2.4	69 ± 6.5	81.6 ± 29.2	81.7 ± 6.9
	Winter	0	24.9 ± 2.8	20.8 ± 2.3	20.8 ± 2.9	55.2 ± 12.2	82.4 ± 60.7	80.8 ± 4.1
Granulator	Pre monsoon	0.7 ± 0.8	30.2 ± 2.8	30.2 ± 3.1	24.9 ± 2.5	54.7 ± 18.5	131.9 ± 119.9	103.1 ± 2.8
	Monsoon	0.9 ± 1.8	32.1 ± 2.9	32.4 ± 2.9	29.1 ± 2.6	72.7 ± 11.6	389.3 ± 148.3	104.3 ± 1.9
	Post monsoon	0	27.2 ± 3.3	27.9 ± 3.7	24.6 ± 3.3	71.2 ± 7.2	317.9 ± 161.8	103.2 ± 2.7
	Winter	0	25.1 ± 2.5	24.7 ± 2.7	20.7 ± 2.1	55.7 ± 6.7	122.9 ± 117.4	102.9 ± 1.8
Injection-molding	Pre monsoon	2.1 ± 1.5	29.4 ± 3.1	30.1 ± 3.3	24.5 ± 3.0	63.3 ± 17.7	202.2± 125.2	75.4 ± 4.8
	Monsoon	2.3 ± 0.9	32.1 ± 3.1	32.8 ± 3.1	28.9 ± 2.4	70.1 ± 9.1	237.1 ± 129.1	81.6 ± 4.7
	Post monsoon	1.8 ± 1.3	27.1 ± 3.1	27.9 ± 3.2	24.2 ± 2.9	68.8 ± 6.9	139.2 ± 95.7	74.8 ± 4.2
	Winter	0.6 ± 0.9	27.1 ± 3.6	28.3 ± 3.31	22.2 ± 2.1	52.3 ± 11.3	207.5 ± 133.7	73.4 ± 3.5

Legends: AWS – Average Wind Speed; DBT – Dry Bulb Temperature; GT – Globe Temperature;
WBGT – Wet Bulb Globe Temperature; RH – Relative Humidity

6.3.2 Significance of difference between observations (among different climatic seasons)

Comparisons of indoor environment parameters at each workstation in different seasons are shown in table 6.2.

Table 6.2

Significance of difference between observations among different climatic seasons

Work-stations	AWS	DBT	GT	WBGT	RH	Illuminance	Noise
Blending	NS	*	*	*	*	NS	NS
Granulator	*	*	*	*	*	*	NS
Injection-molding	*	*	*	*	*	NS	*

Legends: AWS - Average Wind Speed; DBT - Dry Bulb Temperature; GT - Globe Temperature; WBGT - Wet Bulb Globe Temperature; RH - Relative Humidity;
NS - No significant difference ($p > 0.05$); * - Significant difference ($p \leq 0.05$)

6.3.3 Thermal sensation votes

Thermal sensation votes in different climatic seasons among workers in different shop-floor workstations are shown in table 6.3.

Table 6.3

Percentage of thermal sensation votes in the shop-floor workstations

Work-stations	Season	Hot (3)	Warm (2)	Slightly Warm (1)	Neutral (0)	Cool (-1)	Cool Slightly (-2)	Cold (-3)
Blending	Pre Monsoon	-	7.9	38.5	53.6	-	-	-
	Monsoon	-	-	69.2	30.8	-	-	-
	Post Monsoon	-	-	22.2	77.8	-	-	-
	Winter	-	-	25	33.3	25	16.7	-
Granulator	Pre Monsoon	-	-	46.2	53.8	-	-	-
	Monsoon	5.9	17.6	64.7	11.8	-	-	-
	Post Monsoon	-	-	33.3	66.7	-	-	-
	Winter	-	-	-	58.4	33.3	8.3	-
Injection-molding	Pre Monsoon	-	3.8	50	46.2	-	-	-
	Monsoon	-	14.7	73.5	11.8	-	-	-
	Post Monsoon	-	-	5.6	94.4	-	-	-
	Winter	-	4.1	37.5	41.8	8.3	8.3	-

6.3.4 Thermal comfort votes

Thermal comfort votes in different climatic seasons among workers in different shop-floor workstations are shown in table 6.4.

Table 6.4

Percentage of thermal comfort votes in the shop-floor workstations

Work-stations	Season	Much too warm (3)	Too warm (2)	Comfortably warm (1)	Comfortable (0)	Comfortably cool (-1)	Too cool (-2)	Much too cold (-3)
Blending	Pre Monsoon	-	-	38.5	61.5	-	-	-
	Monsoon	-	17.6	47.1	35.3	-	-	-
	Post Monsoon	-	-	-	100	-	-	-
	Winter	-	-	-	75	25	-	-
Granulator	Pre Monsoon	-	-	7.7	92.3	-	-	-
	Monsoon	-	5.9	76.5	17.6	-	-	-
	Post Monsoon	-	-	-	100	-	-	-
	Winter	-	-	-	75	25	-	-
Injection-molding	Pre Monsoon	-	-	26.9	73.1	-	-	-
	Monsoon	-	11.8	44.1	44.1	-	-	-
	Post Monsoon	-	-	-	100	-	-	-
	Winter	-	-	29.2	62.5	4.2	4.1	-

6.3.5 Expectations and overall acceptance of thermal environment in the shop-floor workstations

Expectations of respondents in the shop-floor workstations with regard to air movement, humidity, temperature, along with the overall acceptance of thermal environment during different climatic seasons are shown in table 6.5.

Table 6.5

Expectations and overall acceptance of thermal environment in the shop-floor workstations

Workstations	Season	Expectations (% of response)									Overall acceptance (% of response)	
		Air movement			Humidity			Temperature				
		Lesser	As it is	more	Lesser	As it is	more	Cooler	As it is	Warmer	Yes	No
Blending	Pre Monsoon	-	7.7	92.3	7.7	92.3	-	69.2	30.8	-	61.5	38.5
	Monsoon	-	5.9	94.1	23.5	70.6	5.9	64.7	35.3	-	29.4	70.6
	Post Monsoon	-	55.6	44.4	-	88.9	11.1	11.1	88.9	-	100	-
	Winter	-	66.7	33.3	-	100	-	8.3	91.7	-	91.7	8.3
Granulator	Pre Monsoon	15.8	84.2		7.9	92.1	-	46.2	53.8	-	92.3	7.7
	Monsoon		17.6	82.4	41.2	58.8	-	94.2	5.8	-	11.8	88.2
	Post Monsoon	22.2	11.1	66.7	44.4	55.6	-	33.3	66.7	-	77.8	22.2
	Winter	-	100	-	-	100	-	8.3	75	16.7	91.7	8.3
Injection-molding	Pre Monsoon	-	38.5	61.5	7.7	92.3	-	61.5	38.5	-	92.3	7.7
	Monsoon	-	52.9	47.1	26.5	73.5	-	73.5	26.5	-	82.3	17.7
	Post Monsoon	-	100	-	11.1	88.9	-	5.6	94.4	-	100	-
	Winter	-	79.2	20.8	4.2	95.8	-	16.7	66.6	16.7	87.5	12.5

6.3.6 Use of lights, fan, personal protective devices and clothing behavior in the shop-floor workstation

Use of supplementary lights, fan, ear plug / muff and the type of upper body clothing worn by the worker (in terms of the percentage of occurrences) during the investigations categorized under different climatic seasons are shown in table 6.6.

Table 6.6

Use of lights, fan, personal protective devices and clothing behavior in the shop-floor workstations

Work-Stations	Season	(% of occurrence) Use of supplementary lights: Yes	Use of supplementary lights: No	Use of fan: Yes	Use of fan: No	Use of ear plug / muff: Yes	Use of ear plug / muff: No	Type of upper body clothing: Banyan (vest)	Type of upper body clothing: Shirt / T - shirt	Type of upper body clothing: Woolens
Blending	Pre Monsoon	15.4	84.6		100		100	46.1	53.9	
	Monsoon		100		100		100	41.2	58.8	
	Post Monsoon		100		100		100		100	
	Winter	33.3	66.7		100		100		91.7	8.3
Granulator	Pre Monsoon	23.1	76.9	46.2	53.8	100		15.8	84.2	
	Monsoon	5.9	94.1	11.8	88.2	100		11.8	88.2	
	Post Monsoon		100		100	100			100	
	Winter	41.7	58.3		100	100		8.3	91.7	
Injection-molding	Pre Monsoon		100	80.7	19.3		100	15.4	84.6	
	Monsoon		100	100			100		100	
	Post Monsoon	5.6	94.4	88.9	11.1		100		100	
	Winter		100	75	25		100		87.5	12.5

6.4 Discussion

Temperatures should be kept low as practicable for providing reasonable comfort and measuring instruments may also be provided (The Factories Act, 1948). Acceptable indoor (factory / office buildings) temperature range is 20˚ C - 24 ˚C during winter, 23˚C - 26˚ C for the summer as per ISO 9241, (Bridger, 2002) but variations may occur in ISO standards on account of ethnic and geographic diversity, individual differences, varied thermal environments previously experienced and adaptability (Olesen and Parsons, 2002). Satisfactory ranges for humidity are 60 - 80% for 20 ˚C, 50 - 70% for 22˚C, 45 - 65 % for 24˚C and 40 - 60 % at 26 ˚C; while temperatures ranging between 19 ˚C and 23℃ with 40% - 70% relative humidity are accepted by the majority of workers (Bridger, 2002). Factory workers accustomed to warm humid tropical climatic conditions can tolerate up to 30˚C which may increase to 34˚C if air velocity is 0.6 m/s when performing light manufacturing activities without copious ventilation (Wijewardane and Jayasinghe, 2008). Investigations in an Indian rail terminal (Deb and Ramachandraiah, 2010) showed that the neutral temperature was about 33.01 ºC with air movement. Air movements are an important factor in determining comfort in tropical climates (Nicol, 2004). It was observed from previous studies that air velocity of more than 1 m/s (> 1.5 m/s in some instances among people in warm humid climates) had a major influence on thermal comfort and air movement reduced thermal discomfort when the temperature exceeded 31 °C but below 40 °C (Indraganti et al., 2012). The acceptable range of humidity varies from 30% to 65% and increased air velocities, make most people remain comfortable even at higher relative humidity (Indraganti et al., 2012).

Ambient temperature, relative humidity was not found conforming to recommendations proposed by organizations like ISO in many instances (table 6.1). However, ambient temperature at all workstations is within the suggested tolerable limits proposed by studies performed among people in tropical climates. Significant differences were observed in thermal conditions (DBT, GT, RH and WBGT values) at workstations during different climatic seasons (table 6.2). Majority of workers voted within satisfactory / comfort range in thermal sensation and comfort scales (table 6.3 and 6.4). Globe Temperature (GT) is helpful to measure the true condition of the thermal environment (Bridger, 2002). Globe Temperature indicates the environmental impact on heat stress and is influenced by air temperature, radiant heat, air movement and humidity (Balakrishnan et al., 2010). Sources of heat should be shielded when radiant heat (measured using the Globe thermometer) exceeds ambient temperature by 10 ºC (Corlett and Clark, 1995). The Globe temperature did not exceed the ambient temperature by 10 ºC in all seasons at the shop-floor workstations. The Wet Bulb Globe Temperature (WBGT) index is a measure of environmental heat stress index and is used widely in workplaces (Dash and Kjellstrom, 2011) because of its simplicity and ease of use (Moran and Epstein, 2006). WBGT heat stress index has been proven for reliability, validity, usability and may be used worldwide (Parsons, 2006). The WBGT heat stress index for low, moderate, high, very high workload are 30 ºC, 28 ºC, 26 ºC and 24 ºC respectively (Helander, 1995). The Threshold Limit Value (TLV) of WBGT index is 26.7 ºC for moderate and 25 ºC for heavy continuous work each hour (OSHA, 1999). For 75% work and 25% rest each hour, the TLV is 28.0 °C and 25.9 °C for moderate and heavy workload (OSHA, 1999). Work performed in shop-floor alternates between moderate and high workload based on production plan, and it was observed that heat stress during the monsoon season exceeded TLV in all the workstations (table 6.1). Several studies have proved that heat stress may deteriorate work efficiency and productivity (Wani and Jaiswal, 2012). Manual workers in manufacturing industries among low and middle income countries in tropical regions are exposed to hot working environments and may be at the risk of heat stress and are prone to suffer from heat-related illness even when exposed to little or no direct sunlight radiation (Xiang et al., 2014). None of factories surveyed had provision for mechanically induced air movement like fan in the blending workstation. The location of blending workstation in a remote corner of the shop-floor, possibility of plastic granules and blending color ingredients being blown away while conveying it into the blending machine are reasons for the absence of mechanical aids for air movement. Due to higher noise generation, the granulator workstation without provision for fan was kept separately outside the shop-floor (but without being completely enclosed) in some factories. The workers at the injection-molding workstation were fully or partially under the influence of fan in all factories. Factories at large failed to focus the air movement on the working position. The workers found the thermal environment acceptable majority of times (except for blending and granulator workstations during the monsoon season, table 6.5). Workers in blending and granulator workstations demanded more air movement during the monsoon season (table 6.5). Workers were changing their upper body clothing according seasonal variations and personal preferences (table 6.6). Personal protection measures to avoid heat stress include reflective clothing, body cooling (ice vests, wetted clothing, water-cooled garments and personal cooling system using circulating air) and the respirator (OSHA, 1999). Methods for reducing heat stress in the work environment also include the reduction of relative humidity using dehumidifiers, increased air movement using fans and air conditioners, scheduling frequent rest pauses and job rotation, maintaining hydration by drinking water and taking salt tablets (Helander, 1995). Costly personal protection methods may not be implemented in small and medium sectors in the Indian scenario. Hence, air movements focused on the work position / worker in all the workstations may help in reducing the heat stress, especially during the monsoon season. Suitable arrangements should be provided for increased air movement in blending and granulator workstations. Scheduling frequent rest pauses, job rotation, maintaining hydration by drinking water and taking salt tablets may also be adopted. It is reported from studies in warmer climates that air movement compensates for thermal discomfort at high indoor temperatures without compromising on the overall acceptability of the environment (Indraganti et al., 2012). Many buildings in the tropical countries were observed to have the air temperature above 30 ºC, air velocity in excess of 1 m/s and numerous field studies in hot climates have found that people were comfortable at temperatures up to or even exceeding 30 ºC while using fan (Olesen and Parsons, 2002).

Day lighting was utilized in the factories. For plastic works / processes performed in industrial buildings and involving injection-molding process, an illumination of 200 lux is recommended (Bureau of Indian Standards, 1972) while trimming and cutting activities require a minimum of 300 lux (Bureau of Indian Standards, 1992 c). Illumination Engineering Society (IES) recommends 200 lux to 500 lux for rough bench, machine work and ordinary inspection (Helander, 1995). Illumination levels were below recommended limits in blending workstation (table 6.1) in all seasons. Illumination levels in granulator and injection-molding workstations were below the recommended limits during certain instances (table 6.1). Illumination levels did not vary significantly across blending and injection-molding workstations, while significant variation was seen across granulator workstations (table 6.2). Significant differences were observed in the illumination levels in the granulator workstations during different seasons (table 6.2). The granulator workstations were placed separately outside the shop-floor in some factories due to noise considerations. Glazing on the roof was inadequate and fenestration according to the recommended guidelines (Bureau of Indian Standards, 1972) was not followed in some factories. Ignorance in the layout of machines reduces the intensity of light reaching the working plane due to obstructions (structural members, overhead installations, vertical and horizontal machines) (Bureau of Indian Standards, 1972). This may be one of the reasons for incidences of poor illumination on the working plane in the injection-molding workstations as machines were placed close to one another providing space just sufficient for working personnel. Intensity of indoor illumination during the day hours are bound to vary in accordance with the intensity of outside illumination. There was no mechanism to monitor the illumination intensity in the shop-floor. Hence supplementary lights were not properly utilized regularly when the intensity of illumination was inadequate during the daytime. Lack of appropriate lighting focused on the worker's working position was another contributing factor towards insufficient illumination. Provision for movement of overhead cranes resulted in supplementary lighting arrangements placed very high from the working plane. It was also observed that lighting accessories were utilized to supplement the natural day lighting in some instances (table 6.6). Illumination in the working plane was inadequate to comply with recommended limits even when supplementary lighting was used. Local lighting termed as supplementary lighting is aimed at providing additional luminaries at a small distance from the visual task aimed at illuminating a limited area (Bureau of Indian Standards, 1992 c). Local illumination may be used when general day lighting does not penetrate certain places (because of obstructions) and the recommended intensity of illumination should be maintained at all times, especially when the work is performed indoors (Bureau of Indian Standards, 1992 c). Appropriate illumination (natural or artificial or both) should be provided at all places in the factory where workers are working or passing by (The Factories Act, 1948). Additional glazing using good glazing surfaces and proper fenestrations should be provided wherever needed. Adequate side and top glazing in factories as per recommendations (Bureau of Indian Standards, 1972) will allow more daylight indoors. Supervisors should be equipped with light meters for periodic monitoring of the illumination intensity during daytime and should switch on local illumination focused on the working plane when the illumination intensity falls below the recommended limits. The layout of the shop-floor workstations should be planned as per recommendations in the national building code (Bureau of Indian Standards, 2005 b) for proper illumination at the working area.

Noise exposure has been regulated to 90 dBA for an eight hour period in U.S.A (80 dBA exposures considered harmless), while 85 / 90 dBA being taken as a guide number in Greece (Eleftheriou, 2002). From a survey of various literature it has been highlighted that maximum permissible noise exposure limit of 85 - 90 dBA for 40 hours / week was suggested by ISO, 90 dB(A) for 40 hours / week has been stipulated in the United Kingdom, Denmark and Canada while OSHA has proposed a limit of 90 dB(A) for eight hours / day (Olayinka and Abdullahi, 2009). The maximum noise dosage of 85-90 dBA with a maximum exposure time of eight hours /day for five days / week (40 hours / week) is specified by ISO (Habali et al., 1989; Shaikh, 1999). Recommendation to limit steady noise at 88 dBA in developing countries was put forth as most of the industrial plants in developing countries work eight hours / day for 6 days / week amounting to 48 hours / week (Shaikh, 1999). Indian Factories Act - 1948 specify a limit of 90 dB (A) for an eight hour exposure (Rathod et al., 1987; Singh et al., 2009 a). People exposed to sound level of over 85 dB for several hours a day may be prone to permanent hearing impairment (Ahmed et al., 2011). Mean sound levels at granulator workstation were above recommended limits while the average sound levels in blending and injection-molding workstations were below recommended limits (table 6.1). Machines with high noise levels may be quieted, replaced or isolated (Bridger, 2002). Reducing structure and air borne transmission may help to control noise levels (Helander, 1995). Air borne transmission of noise may be reduced by increasing the distance between source and worker, rotating noise source, using barriers and baffles, enclosing the noise source and workers, applying damping material and use of ear protection (Helander, 1995). Control at the noise source and reducing the structure borne transmissions may not be possible in MSMEs as they require substantial additional investment and engineering expertise. Therefore air borne transmission of noise may be reduced using appropriate measures. Noise level in excess of 100 dBA was observed at granulator workstations. Workers in the granulator workstations were found to be wearing either ear plugs or ear muffs in all the factories (table 6.6). Blending and injection-molding workstation workers did not wear any protective equipment (table 6.6). Ear muffs in addition to ear plugs (OSHA, 1999; Bridger, 2002) must be compulsorily worn by workers in the granulator workstations for better protection. Since majority of workers in blending and injection-molding workstations were working on the work shift duration of 12 hours, it is recommended to wear ear plugs as a precautionary measure. Granulator workstations should be isolated completely which will definitely help in reducing the noise intensities in other workstations in shop-floor. Concrete (good insulator) / fiber glass (good absorber) (Bridger, 2002) may be used to isolate granulator workstations. Significant differences among mean noise intensities were observed in the injection-molding workstations during different climatic seasons (table 6.2). Significant differences may be due to the operation of one, two or more injection-molding machines (at any given point of time), depending on market driven production demands in various seasons.

6.5 Conclusion

Comparisons of prevailing indoor environmental conditions with guidelines specified by scientific organizations and researchers indicated the need for context specific corrective actions. Improvement of physical work environment (air movement, temperature, relative humidity, illumination and noise level) is needed for humanizing working conditions in shop-floors of small and medium scale injection-molded plastic furniture manufacturing industries. **Hence hypothesis – H_3 of the research work is established with respect to indoor work environment**. Replacing worker by mechanization, changing task or environment, protecting the worker are the necessary steps to be adopted if workers are working in unfavorable indoor work environment (Bridger, 2002). However MSMEs in industrially developing countries like India are intended to be labor intensive for the generation of large employment and therefore complete automation of production processes is not feasible. Hence suitable modifications in work methods, immediate working environment and guarding humans may be adopted by existing plastic processing industries for humanizing work and work environment. Problems in prevailing layouts and context specific guidelines from published literature have been highlighted. **Thus the objective - 5 of the research work is accomplished.** Suggestions proposed may be implemented in shop-floors of existing injection-molded plastic furniture manufacturing industries for humanizing the indoor work environment. Research methodology adopted in the present study may be easily adopted for identification of season and location specific indoor work environment risk factors in the industrial workstations of MSMEs in industrially developing countries.

Chapter VII

Redesign of small and medium scale injection-molded plastic furniture manufacturing shop-floor: from view point of ergonomics and indoor environmental issues

Abstract

The small and medium scale manufacturing enterprises have their own industry specific machines arranged in the shop floor for manufacturing finished goods. Investigations pertaining to the shop floor layout designs from physical and environmental ergonomics perspectives have not been performed in the Indian small and medium scale injection-molded plastic furniture manufacturing industries till date. Present chapter aims to investigate shop floor layout design practices in the existing small and medium scale injection molded plastic furniture manufacturing industries in order to propose context specific guidelines based on physical and environmental ergonomics aspects. Factories were visited for studying the existing shop floor layout designs. Prevailing layout designs were evaluated by comparison with guidelines proposed by various researchers and scientific organizations. It was observed that physical and environmental ergonomics guidelines were not considered while designing shop floor layouts in the small and medium scale injection molded plastic furniture manufacturing industries. The problems in the prevailing layouts have been highlighted and context specific guidelines have been proposed. A conceptual shop floor layout was developed incorporating recommended guidelines. Virtual shop floor layout representation was rendered for easy visualization of proposed guidelines. Research outcome is expected to be immensely beneficial for the existing and upcoming small and medium scale injection molded plastic furniture manufacturing industries in India.

7.1 Introduction

Plant layout deals with issues concerning the spatial arrangement of machines, tools, and workplace and storage places; while a good, well-planned layout significantly increases the process efficiency besides ensuring safety (Bureau of Indian Standards, 2008). Major design approaches towards facility layout focus on two types of layouts namely product and process (Kroemer, 1997). Machines of the same type are grouped together in process layout while all machines needed for manufacturing a particular product are grouped together in product layout (Kroemer, 1997). In addition to the above two types of layout there are other variations like group technology (cellular) layout, fixed position layout and combination layout. Redesigning layouts to rectify problems incurs huge cost and takes away the precious production time (Lin and Sharp, 1999). Hence it is advisable to plan for a new facility based on the process and the product (Kroemer, 1997). However, prevailing facilities layout methods focus little on ergonomics / human factors (Lan and Zhao, 2010). Ergonomics is a discipline which tries to adapt the man-made world to people concentrating on human as the most important component in technical systems, hence this discipline is human-centered, trans-disciplinary and application-oriented (Kroemer, 1997).

In India research has been conducted on layouts resulting in proposing design methodology for cellular manufacturing using lean manufacturing concepts in ammunition components manufacturing industry for defense applications (Pattanaik and Sharma, 2009), conversion of functional layout to cellular layout based on queue time performance involving lathe, milling and drilling centers (Pitchuka et al., 2006), cellular manufacturing layout based on processing time (Angra et al., 2008), improving employee and manpower productivity by plant layout improvement in the small scale manufacturing plant of flour machines (Jain et al., 2014), development of a manufacturing facility layout planning using fuzzy facility selection routine (Deb and Bhattacharyya, 2005), development, integration optimization and simulation tools for conversion of functional layouts into cellular layouts (Eswaraiah and Rao, 2005), implementing layout determined by cellular manufacturing principles in automotive butyl inner tubes process industry (Kumar and Ramesh, 2012), determining optimum layout aimed to minimize cost by reducing the total travelling distance of materials processed using cellular manufacturing in process industry (Anbumalar et al., 2014) and modification of layout considering the sequence of operation in a valve manufacturing industry (Ashok and Rajaram, 2013). It is evident that research work with regard to layout in India has mainly focused on engineering concerns while ergonomics of the design factors and indoor work environment requirements were not significantly considered.

Investigations pertaining to shop-floor layout designs from ergonomics (human factors) and indoor environment perspective have not been performed in small and medium scale injection-molded plastic furniture manufacturing industries till date. Shop-floor layout design investigations in existing injection-molded plastic furniture manufacturing factories will help to identify problems and propose guidelines based on ergonomic design considerations and indoor work environment factors. Computer Aided Design (CAD) helps in visualization of layout in 2D and 3D forms and is widely used to determine the safest and the most efficient arrangement of production machines and equipment (Bureau of Indian Standards, 2008). Factories were visited for studying existing shop-floor layout designs. Prevailing layout designs were evaluated by comparison with guidelines proposed by various researchers and scientific organizations. It was observed that ergonomics and indoor environmental factors were not considered while designing shop-floor layouts in small and medium scale injection-molded plastic furniture manufacturing industries. Problems in prevailing layouts and context specific guidelines from published literature have been highlighted. A conceptual shop-floor layout was developed incorporating recommended guidelines. The CAD model of the conceptual shop-floor layout has been constructed for easy visualization. Research outcomes will be immensely beneficial for small and medium scale injection-molded plastic furniture manufacturing industries.

7.2 Aim

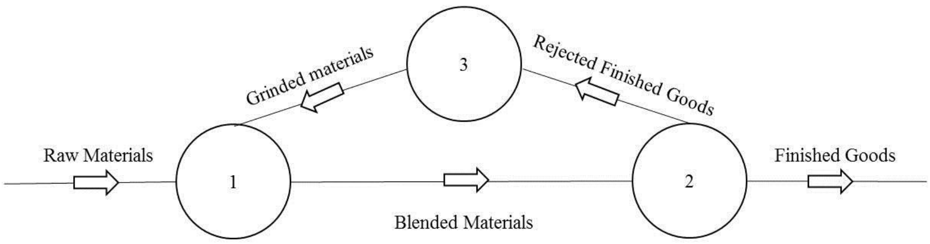
To investigate the shop-floor layout design practices in existing small and medium scale injection-molded plastic furniture manufacturing industries in order to develop context specific guidelines based on ergonomics and indoor environment perspectives.

7.3 Methodology

Four (04) injection-molded plastic furniture manufacturing industries under the small and medium sector in the state of Assam were visited. Production processes, the arrangement of machines and flow of materials were observed. Flow diagram with the help of process chart symbols was drawn to represent the existing facility layouts and material flow. Literature concerning facility planning, national building codes, anthropometric dimensions, indoor industrial physical work environmental parameters, product dimensions and behavioral space dimension factors were consulted for gathering applicable information in order to identify potential problems and formulation of context specific design guidelines. CAD was used for virtual representation of the conceptual layout.

7.4 Production process in the injection-molded plastic furniture manufacturing industries

The entire production process culminating in the production of finished goods is completed with the help of three workstations featuring blending; granulator and injection-molding machines (figure 7.1).



1 – Blending Workstation; 2 – Injection Molding Workstation; 3 – Granulator Workstation

Figure 7.1 Shop-floor workstations and the flow of materials

7.5 Flow diagram of Shop-floor layout in different factories

The flow analysis is one of most widely used techniques for determining the best arrangement of equipment (Meyers and Stephens, 2000). Analysis using flow diagrams (which have no standard form) using process chart symbols (table 7.2) are shown on the layout.

Table 7.1

Process chart symbols

Process chart symbol	Description
○	Operation
□	Inspection
⇨	Transport
▽	Storage
D	Delay

(adopted from Kroemer, 1997)

The injection-molding machines were grouped and placed together in factories visited. Blending and granulator machines were placed individually or in groups (depending on the number on machines) at locations deemed fit, based on space, noise level considerations and the form of factory building. The process type of layout (material flowing through machines as a product layout) which may be categorized as the combination layout was observed in the factories visited (figure 7.3,7.4,7.5 and 7.6).

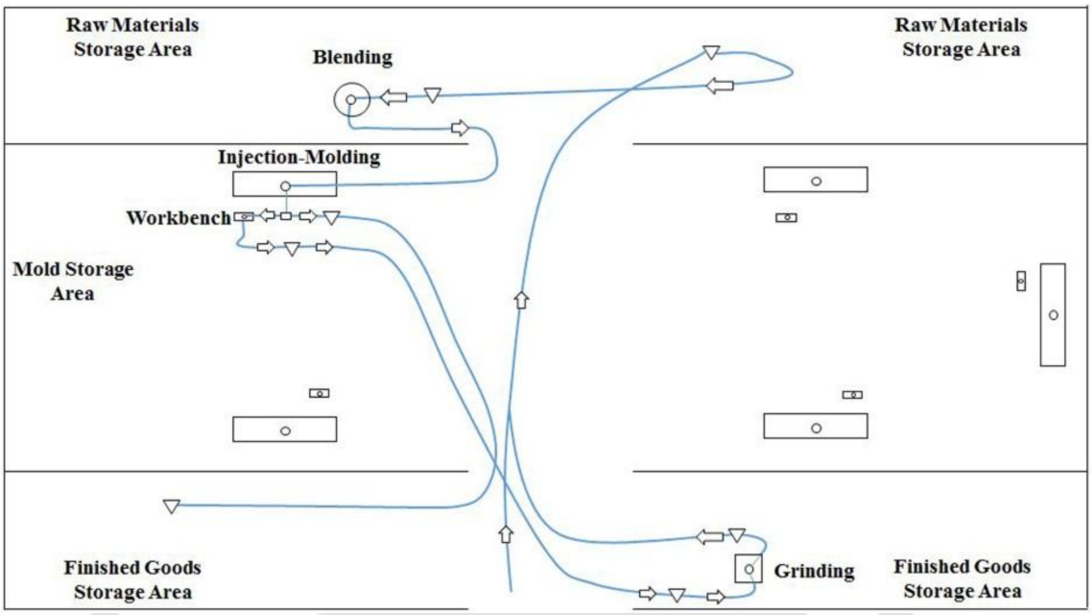


Figure 7.2 Shop-floor layout and material flow of factory A

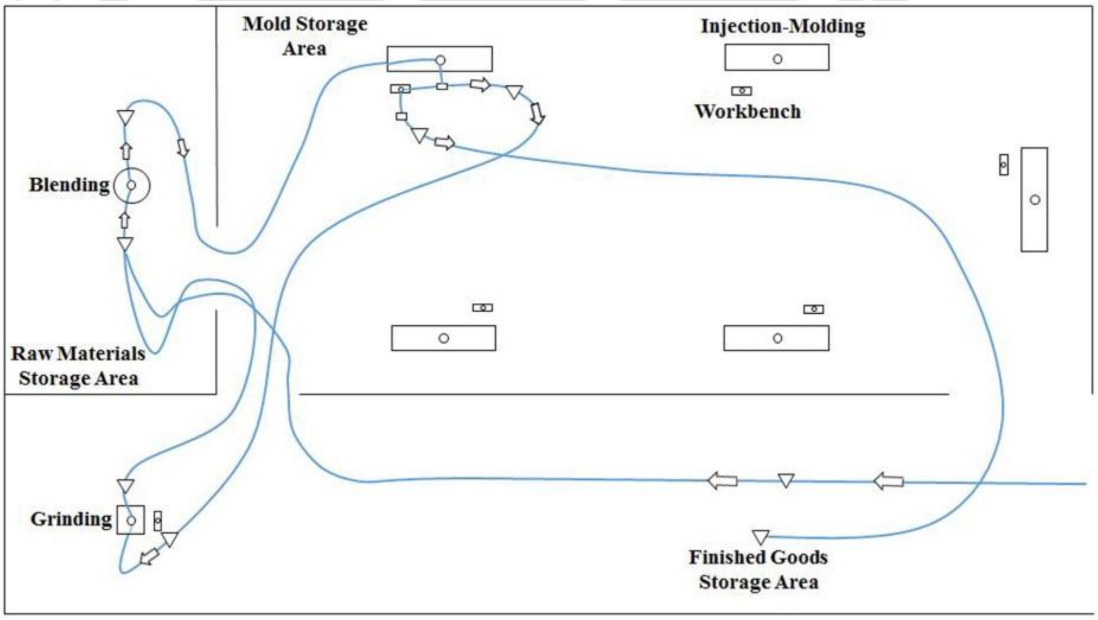


Figure 7.3 Shop-floor layout and material flow of factory B

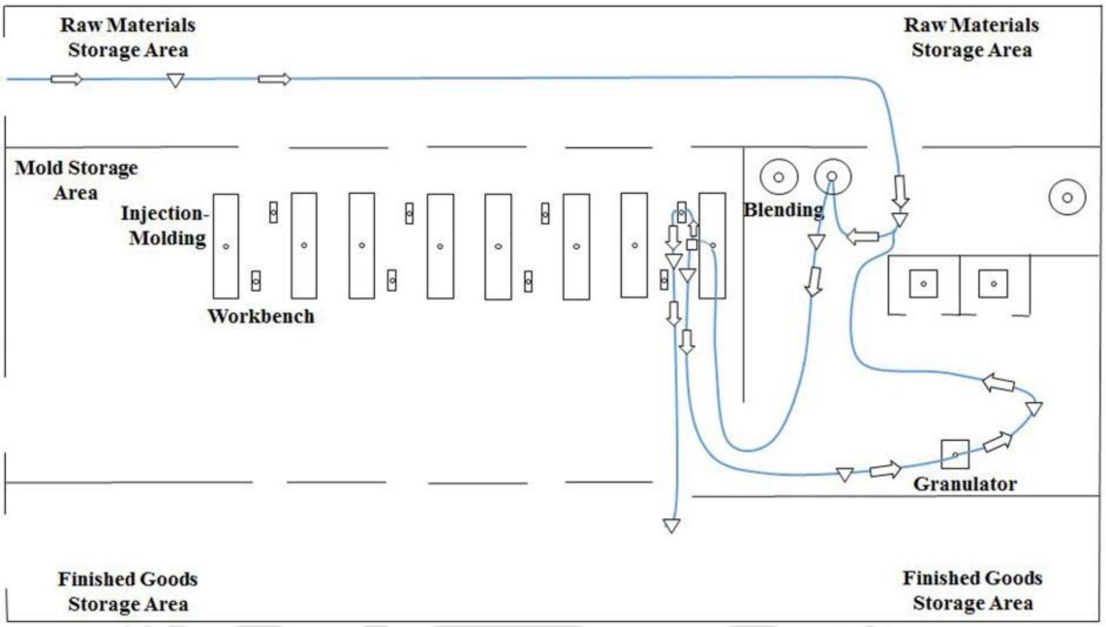


Figure 7.4 Shop-floor layout and material flow of factory C

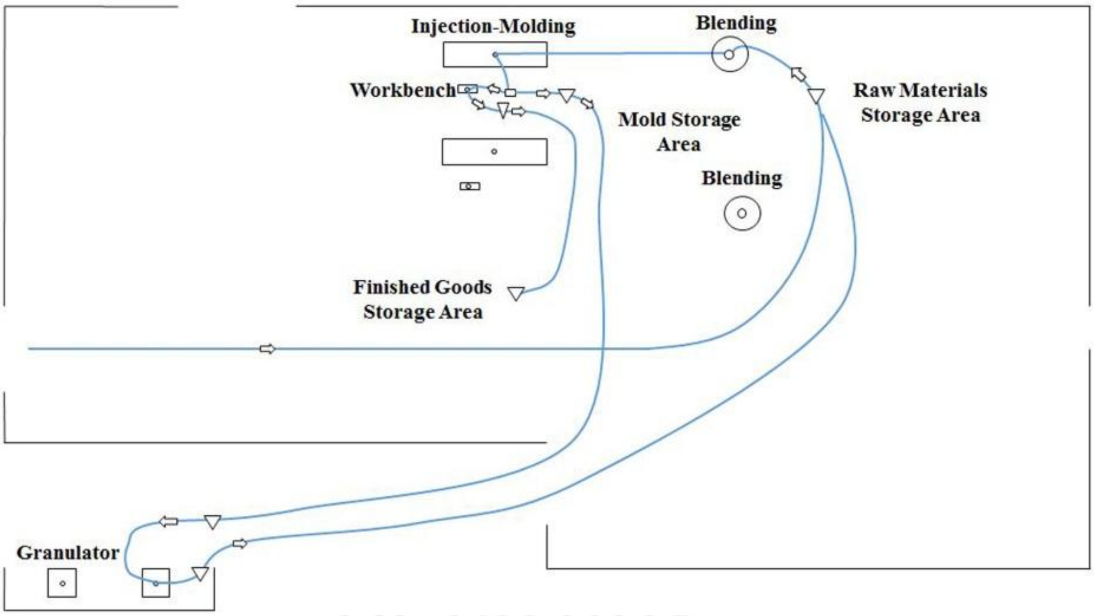


Figure 7.5 Shop-floor layout and material flow of factory D

7.6 Identification of problems in the existing shop-floors from ergonomics and indoor environment perspective

Existing shop-floor layouts (figure 7.3, 7.4, 7.5 and 7.6) were commissioned based on plant site dimensions, space availability within the plant layout, the number of machines installed, building plan and material movement. Ergonomics and indoor environmental concerns were not considered while designing and implementing shop-floor layouts. Hence the absence of windows at appropriate locations (for facilitating proper illumination and ventilation on the working plane), lack of recommended dimensions / requirements for various design features (escape routes, aisle or walkway, doors, windows, space for standing working person, social consultative zone, casual-personal zone, material handling space, clearance between machines, clearance between machine and walls, storage space for work in progress), long material handling distances, improper isolation of noisy machines and inappropriate wall colors were the main problems identified with respect to ergonomics and indoor work environment perspective. Some of the shortcomings of existing designs are pictorially represented (figure 7.7).

Figure 7.6 Pictorial representations of drawbacks in the existing shop-floors

7.7 Recommended design guidelines for shop-floor layout from ergonomics and indoor environment perspectives

Industrial buildings should necessarily be provided with two exits in every floor and for high hazard industrial buildings, the exits should be placed in such a way that it may not be necessary for a person to travel more than 22.5 m from any point within the factory to reach the nearest exit (Bureau of Indian Standards, 1988; Bureau of Indian Standards, 2005). Minimum dimension of escape routes should be at least at least 0.7 m and preferably 1.2 m wide in order to facilitate passage of approximately 40 persons per min (Bureau of Indian Standards, 2008). For accomplishing easy accessibility, the minimum effective clear width of external doors should be 1000 mm in new buildings and 775 mm in existing buildings, while a width of 1800 mm will permit two wheelchair users to pass each other and an area of the circle of minimum 1800mm diameter should be provided for turning purpose (Lacey, 2004). Individual requirements should be considered for employee entrance and generally the door size may measure from 3 feet to 6 feet with an aisle or walkway, while for allowing two way people movement, the aisles must be at least 5ft wide (Meyers and Stephens, 2000). Door dimension should be 80" (height) x 36" (breadth) while a provision for an allowance area of 3 m in front and 1 m on both sides of the main entrance door in addition to 50 cm in front of any window should be provided (Woodson et al., 1992). The minimum required width of the exit doorway should be 1000 mm while the height should not be less than 2000 mm (Bureau of Indian Standards, 2005). The space requirement for a standing person must comprise of a 95th percentile arm span (of male) along with an allowance of 25 mm all-round for clothes (Pheasant and Haslegrave, 2006).

It has been understood that for a social consultative zone which maintains a certain formality between groups of people working together, the range of distance is 1200 mm to 2200 mm while a casual-personal zone for a close relationship (accepting a minimal contact e.g. a handshake or a touch of the finger tips) is found to be around 450 mm – 1200 mm (Chakrabarti, 1997). Maintaining a safe man to man distance (while walking) for a single person may require a length of 50th percentile akimbo length, while two span akimbo spaces can allow 3-4 persons to walk together with a little front to back alignment (Chakrabarti, 1997).

Permanent aisles and passage ways should be marked appropriately and in a consistent manner throughout the factory while the width of marking may range from 2 inches to 6 inches (OSHA, 2013 b). The minimum aisle width ranging from 4 to 6 m has also been specified taking into account heavy traffic and passage of industrial trucks (Bureau of Indian Standards, 2008). The safe design layout of aisles should provide sufficient radius of at least 2 m for allowing the industrial trucks to turn safely and for avoiding blind corners (Bureau of Indian Standards, 2008). At the same time aisles should be clearly defined with appropriate markings of either traffic paint or stripping material and aisles should be clearly identified around every machine in a workshop (Bureau of Indian Standards, 2008).

Layouts should incorporate a minimum sufficient width of 2.0 m for removal, transfer of material and if material handling equipment is used, the minimum width should be 2.5 m (Bureau of Indian Standards, 1991c). Stacking should not be more than 4.50 m in height (where no automatic sprinklers are installed) as it will be very difficult and the stack may be unstable under fire fighting conditions, while clearance of the top of the highest storage level from the undersides of the lowest beams and girder or other ceiling projections should be less than 1.0 m (Bureau of Indian Standards, 1991c). However, it should be kept in mind that stacked material piles should be separated by aisle ways (the width of which should equal the height of higher pile) not less than 3.0 m (Bureau of Indian Standards, 1991c).

Minimum height of industrial ceiling should be 3.6 m (except when air conditioned) and industrial buildings of low and moderate hazard are permitted up to 18 m height whereas high hazard buildings are permitted up to 15 m (Bureau of Indian Standards, 2005).

Machine arrangements should necessarily consider work environmental factors like illumination, noise levels, etc. (Bureau of Indian Standards, 1972; Helander, 1995; Bridger, 2002; Bureau of Indian Standards, 2005). Machines producing loud noise may be isolated by acoustic enclosures for the purpose of reducing noise in the shop-floor (Bureau of Indian Standards, 2008). Other measures include quieting (silencing) or replacing the machine (Bridger, 2002). Increasing distance between source and worker, rotating noise source, using barriers and baffles, enclosing the noise source and workers, applying damping material and use of ear protection may reduce the air borne transmission of noise (Healander, 1995). If factors pertaining to the size of the machine, working area and operation are not suitable for use of barriers and close fitting enclosures; then the machine should be housed in a room of its own and inside of enclosure may be provided with sound absorbing materials in order to reduce the noise level of contained sound (Bureau of Indian Standards, 1966). It is very important that while designing layout the ventilation aspect should also be considered for ensuring worker's comfort (Bureau of Indian Standards, 2008). Adequate provisions should be made for providing ventilation by circulation of fresh air (The Factories Act, 1948). While designing the opening for ventilation, sill level may be provided about 150 mm below the worker's head level (Bureau of Indian Standards, 2005). Opening for ventilation should be provided at the sill level of about 150 mm below the head level of workers (Bureau of Indian Standards, 2005). It is reported that maximum air movement at a particular plane is achieved if sill height is kept at about 85 percent of critical height (head level) (Bureau of Indian Standards, 2005). When window height is 1.1 m, air motion is highest in the working zone (Bureau of Indian Standards, 2005). A suitable number of circulating fans must be installed in all interior working areas especially during the summer months in hot dry and warm humid regions (when ventilation on account of wind action does not provide sufficient relief) for providing the necessary air movement (Bureau of Indian Standards, 2005). If industrial buildings are wider than 30 m, ventilation through windows should be improved by making provisions for roof ventilation (Bureau of Indian Standards, 2005). Light falling on the working plane will not be adequate if the proposed machine layout is not considered properly, and it is essential that good distribution of light covering the entire interior should be made possible (Bureau of Indian Standards, 1972). Shadows (caused by machines and operators) falling on the working planes may be reduced with provisions of openings in side walls and by the use of light colored finish for ceiling surfaces (Bureau of Indian Standards, 1972). The height of the window should be about 1.6 m and width about two-third of wall width and should be located at a height of 1.1 m above the floor and it is suggested that a particular place in a room should not be assumed to be lighted if it is more than 7.5 m away from the opening assumed for lighting a particular portion (Bureau of Indian Standards, 2005). General supplementary artificial lighting is needed when daylight diminishes below 100 lux due to solar altitude falling below 15°, during dark cloudy conditions, if the innermost areas of building are not adequately provided with day lighting, lack of properly sized windows and unavoidable external obstructions (Bureau of Indian Standards, 2005). The suitable height for mounting the luminaires should be between 1.5 m and 2.0 m above the work plane, and luminaires should be separated by a distance between 2.0 m to 3.0 m, with provision for more lamps in the rear half of the room than near the windows, while in the vicinity of windows only single tube luminaries should be provided (Bureau of Indian Standards, 2005). For improved illumination within interiors a white finish for ceiling and off white (light color) to white color for walls should be applied (Bureau of Indian Standards, 2005).

Process layout enables machines to be busy as different products flow through the workstations (Kroemer, 1997). However, process layouts are characterized by increased floor space, lack of fixed material flow paths and a relatively large amount of material handling (Kroemer, 1997). The combination of process and product layout is advantageous and stand-alone product or process layouts are very rare to find in today's manufacturing industries (Ashok and Rajaram, 2013). Short material handling distances is a characteristic of a well-designed layout (Kroemer, 1997). However, it should be kept in mind that overall plant layout is determined by many factors like plant site orientation, availability and requirement of space, provision for future expansion of existing plant, processes, type and quantity of products manufactured, safety and maintenance considerations, accessibility, material movements and routes for emergency exits (Bureau of Indian Standards, 2008).

7.8 Design of concept shop-floor layout

Taking into considerations the recommended design guidelines for shop-floor layout, a concept shop-floor layout was designed based on ergonomics and indoor environment perspectives (Sanjog et al., 2015 c).

7.8.1 2D representation of concept shop-floor layout

A concept layout was visualized (incorporating appropriate recommendations) along with material flow lines (figure 7.7) to minimize shortcomings observed in the existing layouts. The concept floor plan of machine shop, representing clearance space (between walls and machines, between machines) dimensions, the dimensions of aisle pathways and exit passages) is depicted (figure 7.8).

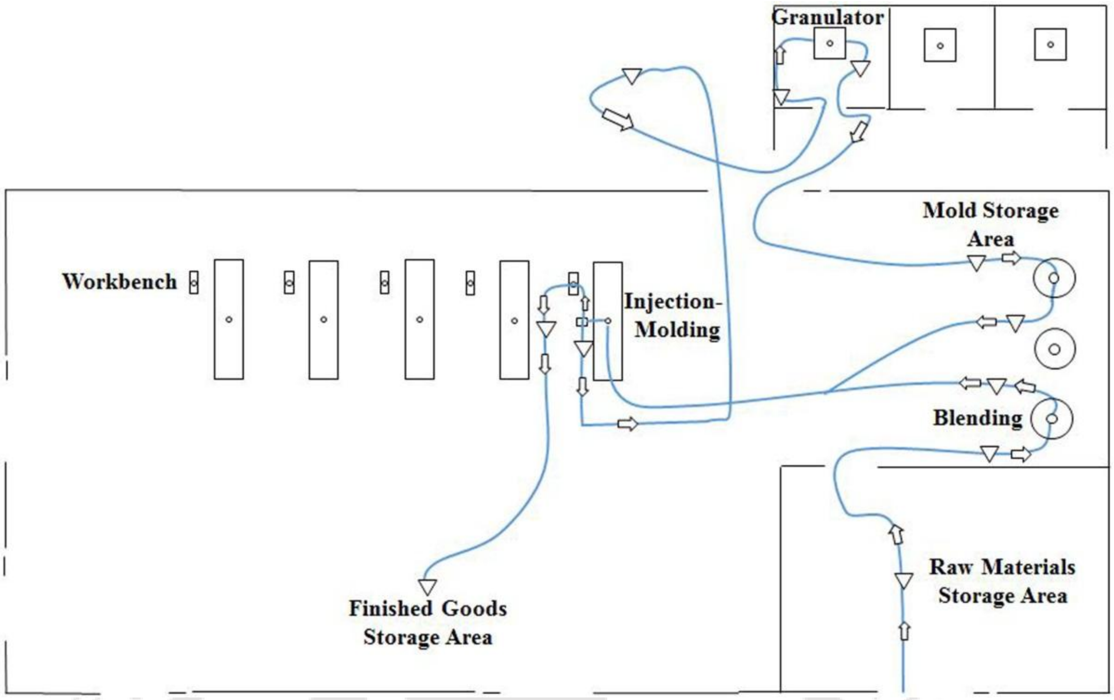
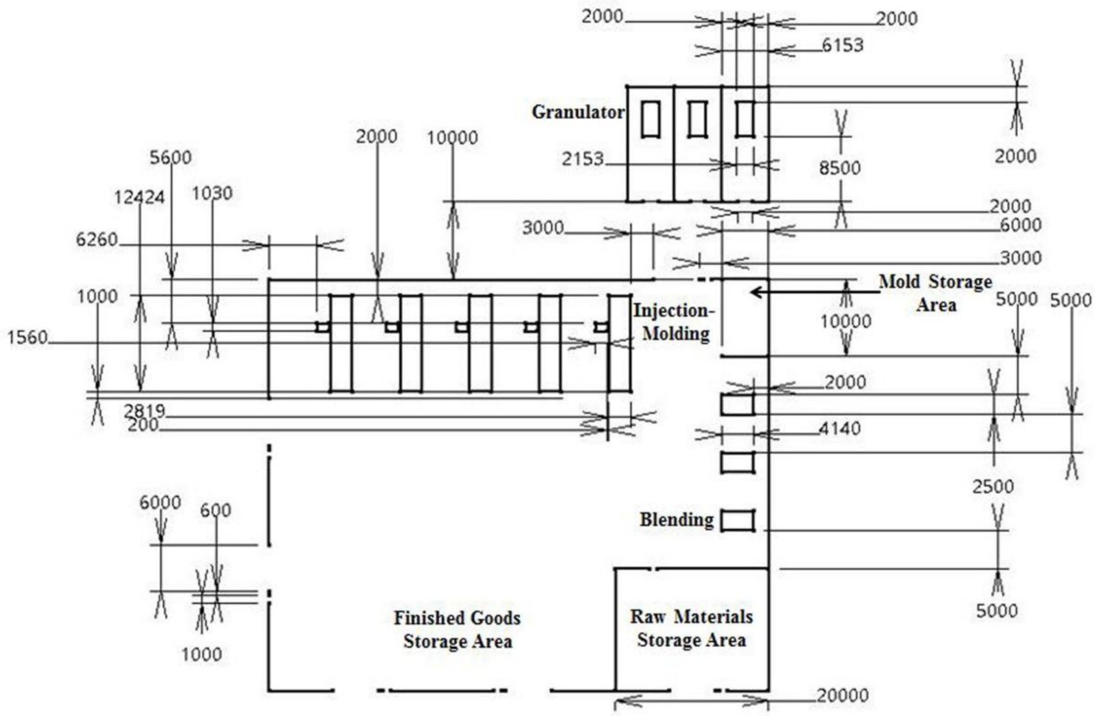


Figure 7.7 Concept plan of shop-floor and material flow



Note: All dimensions in millimeters

Figure 7.8 Concept shop-floor plan with dimensions

7.8.2 Virtual representation of concept shop-floor layout

The virtual representations of the concept shop-floor layout is shown (figure 7.9 and 7.10) for easy visualization.

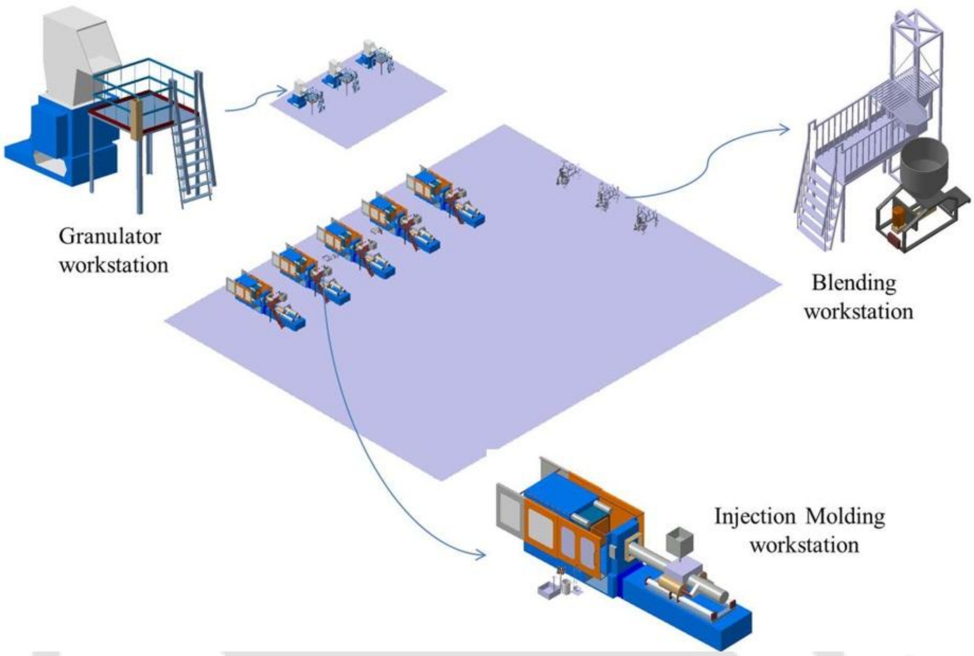


Figure 7.9 Virtual representation of shop-floor workstations in concept shop-floor layout

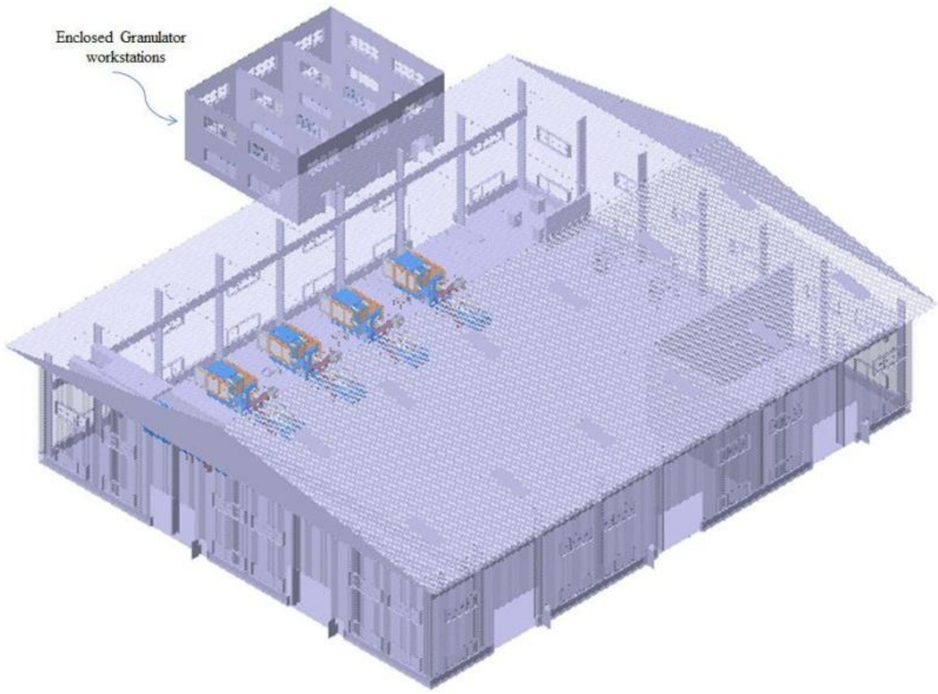


Figure 7.10 Virtual representation of factory building in the proposed shop-floor layout

7.9 Discussion and Conclusion

Prevailing layout designs were evaluated by comparison with guidelines proposed by various researchers and scientific organizations. It was observed ergonomics and indoor environmental factors were not considered while designing shop-floor layouts in the Indian small and medium scale injection-molded plastic furniture manufacturing industries. Problems in prevailing layouts and context specific guidelines from published literature have been highlighted. **Thus the objective - 6 of the research work is accomplished.** Improvement of shop-floor layout is needed for humanizing the working conditions in shop-floor. **Hence hypothesis - H_3 of the research work is established with respect to the redesign of the shop-floor layout**. A conceptual shop-floor layout was developed by incorporating recommended guidelines. Virtual representation (figure 7.9 and 7.10) of shop-floor layout was rendered for easy visualization of the proposed guidelines. In the present concept shop-floor layout, a combination of the process and product layout was followed. Material flow distances between different categories of workstations are minimized as visualized in the concept shop-floor. All workstations are near the wall and necessary provision for natural illumination is provided with the help of windows placed suitably. Further granulator machines which produce much noise are enclosed and kept separately near the main shop-floor. The mold storage area is within the shop-floor as it has to be accessible by the overhead cranes. Further research focusing on engineering considerations would improve the conceptual layout without negating the physical and environmental ergonomics based guidelines proposed in the present research work. Research outcomes presented will be immensely beneficial for existing and forthcoming small and medium scale injection-molded plastic furniture manufacturing industries in India.

Chapter VIII

General discussion and conclusion of the overall thesis

Abstract

The aim of this chapter is to present the general discussion and conclusion of the overall thesis. Lack of research and application of ergonomics in the Indian durable goods manufacturing sector, expected growth of plastic processing industries, need for research initiatives from ergonomics perspectives, injection-molded plastic furniture manufacturing industries in India, selection of factories for conducting research, research methodology, salient findings, mitigation of risk factors, scope for increased productivity through design interventions, harmony of the research initiative and proposals with the policies of Government of India, feedback from production managers / supervisors, limitation and scope for future work have been discussed. Finally, the conclusion incorporating the contribution of the research work is also presented.

8.1 Discussion

8.1.1 Lack of research and application of ergonomics in Indian durable goods manufacturing sector

Very limited efforts have been taken to towards investigations in the Indian durable goods manufacturing sector from an ergonomics perspective. Existing studies in the Indian manufacturing sector, especially in micro small and medium manufacturing enterprises reveal the prevalence of risk factors. Ergonomics (or human factors) issues has largely been ignored during the installation and commissioning of manufacturing industries in MSMEs.

8.1.2 Expected growth of plastic processing industries in North East India

India is poised to witness a tremendous growth in the durable goods manufacturing sector in terms of manufacturing output and generation of employment opportunities. Government if India is providing incentives towards the establishment of micro small and medium enterprises. MSMEs in manufacturing sector increase the manufacturing output and also generate huge employment at low capital cost. The plastic processing industries in India is largely fragmented consisting of small and medium scale industries. Commissioning of petrochemical projects is helping in establishing plastic processing industries and also promoting employment opportunities. Commissioning of Assam gas cracker project is expected to increase plastic processing industries in the state of Assam (a north-eastern state of India) and the entire North Eastern region of India, with the creation of numerous direct and indirect job opportunities.

8.1.3 Need for research initiatives in Indian plastic processing sector from ergonomics perspectives

Foreseeing the enhanced growth potential of plastic processing activities in India and particularly in North East India, it is firmly believed that it is the right time to conduct investigations from an ergonomics perspective in the existing plastic processing industries. Such an initiative will help to identify problems and find ways of addressing those problems through suitable research methodologies. Context specific solutions will benefit the workforce. Long term benefits will accrue for company managements in terms of improved occupational work environment resulting in higher morale of workers, increased work satisfaction and increased productivity.

8.1.4 Injection-molded plastic furniture manufacturing industries in India

Injection-molded plastic furniture manufacturing is an important constituent of plastic processing sector. The injection-molding process is highly advantageous as the injection-molding process has the capability to rapidly produce finished goods of desired shapes in large numbers.

8.1.5 Selection of factories for conducting research

Seven injection-molded plastic furniture manufacturing factories (under small and medium sector) in the state of Assam (a north-eastern state of India) were identified for conducting research. Permission was granted by four company managements for conducting investigations from an ergonomics perspective.

8.1.6 Research methodology

Questionnaire survey was performed to gather demographic information about the workers, the prevalence of symptoms of musculoskeletal ailments and also to identify the discomfort in various body parts. Hand grip strength was measured before and after work among the workers in the shop-floor workstations. Activities performed in the shop-floor workstations were photographed to understand and record the work activities performed. Postural assessment tools were used to identify risky working postures. CAD models of the workstations were generated and interfaced with digital human models in order to investigate the working postures and activities from an ergonomics perspective. Information pertaining to the psychosocial work environment and subjective workloads was gathered towards identification of related risk factors. Indoor work environment parameters (air movement, temperature, relative humidity, illumination and noise level) were measured for a period of one year at shop-floor workstations across the factories. Shop-floor layouts in the selected factories were also investigated from ergonomics and indoor work environment perspectives.

8.1.7 Salient findings in the shop-floor workstations

The following are salient findings observed from an ergonomics perspective with respect to the shop-floors of the Indian small and medium scale injection-molded plastic furniture manufacturing industries.

1. Symptoms of musculoskeletal ailments and occurrence of awkward working postures were observed among workers in shop-floor workstations.
2. Awkward working postures, prolonged work shift duration and bad workstation design were established as significant risk factors for the high prevalence of symptoms of musculoskeletal ailments among the workers in shop-floor workstations. The influence of working postures and workstation design on the symptoms of musculoskeletal ailments was found to be significantly ($p < 0.05$) mediated through work shift duration. Thus the symptoms of musculoskeletal ailments due to awkward working posture and bad workstation design are exacerbated due to prolonged work shift duration.
3. Significant reduction in hand grip strength before and after work in both the hands was observed among shop-floor workers.
4. Shop-floor workstations comprise of equipment made within the country and imported from other countries. Other workstation fixtures / accessories and hand tools are designed by native people lacking basic ergonomics knowledge. Therefore, physical mismatch between the worker's anthropometry and overall workstation design was observed.

5. Comparisons of prevailing indoor environmental conditions with guidelines specified by scientific organizations and researchers indicate the need for context specific corrective actions.
6. Ergonomics and indoor environmental aspects were not considered while designing shop-floor layouts.

8.1.8 Mitigation of risk factors in the context of small and medium scale injection-molding plastic furniture manufacturing industries' shop-floor workstations

Micro small and medium industries in the manufacturing sector of industrially developing countries like India are intended to be labor intensive for the generation of large employment and therefore complete automation of production processes is not feasible. Hence suitable modifications in workstation design, work methods, shop-floor layouts, immediate working environment and guarding humans may be adopted by the existing injection-molded plastic furniture manufacturing industries for humanizing work and work environment.

It was established (see Chapter II, section 2.10) through statistical modeling (that occurrence of symptoms of musculoskeletal ailments due to awkward working postures and bad workstation design is exacerbated if work shift duration is longer. **Thus the hypothesis - H_1 of the research work is established**. Regulating work shift duration could be the possible intervention strategy for downgrading the symptoms of musculoskeletal ailments, if scope for workstation and work method redesign towards avoidance of awkward posture is limited in the shop-floor workstations of small and medium scale injection-molded plastic furniture manufacturing industries. Significant reduction in hand grip strength before and after work among shop-floor workers point to the fact, that the workers are prone to develop serious musculoskeletal disorders in near future. Concept shop-floor workstation models were designed and evaluated virtually using digital human modeling software. Research outcome towards the redesign of workstation and subsequent modification of work methods considering demographic constraints and in accordance with recommended guidelines enabled significant downgrading the risk perception of operational postures (see Chapter IV, section 4.15). **Thus the hypothesis - H_2 of the research work is established**. Good working postures promote better occupational health. Work study techniques were employed to perceive the effectiveness of design interventions on work activities. Design interventions in granulator and injection-molding workstations helped to reduce the number of work elements in the work cycle. However, the proposed design interventions for the blending workstation resulted in the increased number of work elements in a work cycle, but operational postures were safe. Sometimes low cost design interventions focused on safe working postures without automation result in increased work activities, especially when manual lifting of heavy loads are involved. Prevalence of the indoor work environment risk factors (identified by location specific and season specific investigations) may be mitigated by implementation of appropriate recommendations (see Chapter VI, section 6.5). Similarly, present shop-floor layouts (which did not consider physical and environmental ergonomics aspects) can be designed by incorporating guidelines based on ergonomics and indoor environmental perspectives for humanizing work and work activities (see Chapter VII, Section 7.9). **Thus the hypothesis - H_3 of the research work is established**.

8.1.9 Scope for increased productivity through design interventions from ergonomics perspectives

The research work resulted in the formulation of guidelines for better workstation design, improved indoor working environment and shop floor layout from an ergonomics perspective. Implementation of the proposed guidelines is positively expected to improve productivity. Productivity problems are addressed through better machines by engineers and better trained workers by personnel management people, while ergonomists count on the healthier task design characterized by better interface and improved interaction between the user and the machine (Bridger, 2002). Various researchers have opinioned that improved task design, good working postures, appropriate workplace layouts, less discomfort in body parts and simple ergonomics design interventions and better indoor work environment result in increased productivity. Some views supporting increased productivity through the application of ergonomics design interventions are mentioned below.

Studies have shown that good anthropometric fit between workers and their equipment has resulted in improved productivity (Bridger, 2002). Good working postures and workplace layouts maximize the worker's working speed thereby improving productivity (Resnick and Zanotti, 1997). Modifications in the working conditions (like work methods) may be attempted to reduce the incidence of health related problems and to increase productivity (Bhattacharyya and Chakrabarti, 2012). Productivity can be increased if work is performed at the optimum working height and also with less discomfort to the body parts (Vink et al., 2006). Ergonomic improvements in order to reduce the work related musculoskeletal disorders typically increase productivity (Hendrick, 2008). Health and safety at workplaces tend to increase productivity (Niu, 2010). Simple, effective and affordable techniques help to improve working conditions and productivity in small and medium enterprises (Niu, 2010). The positive association between awkward trunk posture and fatigue, reduced productivity was observed in a case study (Corlett and Bishop, 1976). Better working conditions result in improved productivity on account of lower health problems, accidents and absenteeism (Dul et al., 2012). The physical work environment like lighting significantly influences productivity (Lehto and Buck, 2008). Working capacity of the people is influenced by excessive heat leading to decreased productivity (International Labour Office, 2010). Studies have proved that proper illumination and reduced noise levels has resulted in increased productivity (Bridger, 2002).

8.1.10 Harmony of the research initiative and outcomes with the policies of Government of India

The Government of India is committed to ensure safe and healthy working conditions for all working men and women in the country as it recognizes the fact that safety and health of workers has a positive impact on productivity, economic and social development (National Policy on Safety, Health and Environment at Work Place, Ministry of Labour and Employment, 2009). Safe and a healthy working environment is a fundamental human right and without safe, clean environment as well as healthy working conditions, social justice and economic growth cannot be achieved (National Policy on Safety, Health and Environment at Work Place, Ministry of Labour and Employment, 2009). The aim of the National Policy on Safety, Health and the Environment at workplace is to ensure occupational safety, health and environment through proactive approach as well as enhancing the well-being of the employee and society (National Policy on Safety, Health and Environment at Work Place, Ministry of Labour and Employment, 2009). National Policy on Safety, Health and Environment at Work Place also aims to provide practical guidance and encourage employers and employees to reduce the incidence of occupational safety and health risks (National Policy on Safety, Health and Environment at Work Place, Ministry of Labour and Employment, 2009). One of the initiatives of the Ministry of Labour and Employment for making India a better workplace for all is to conduct national, regional, state-level studies/surveys and unit-level studies/ surveys / audits in Occupational Safety and Health (Ministry of Labour and Employment, 2015).

Present research work resulting in guidelines for improvement of shop-floor working conditions from an ergonomics perspective is a positive step in the right direction (in harmony with the intentions of the Government of India) for ensuring a safe and healthy occupational environment with specific reference to small and medium scale injection-molded plastic furniture manufacturing industries.

8.1.11 Feedback from production managers / supervisors with regard to proposed design interventions

The opinions of production managers / supervisors (with respect to the guidelines proposed in the present research work for the improvement of shop-floor working conditions from an ergonomics perspective) were gathered using a questionnaire **(Appendix XII)**. The questionnaire was prepared using information from various literature sources (Hendrick, 1996; Haims and Carayon, 1998; Loisel et al., 2001; Laing et al., 2005; Morel et al., 2009; Wu et al., 2010).

The Cronbach's alpha is the most common measure of internal consistency (reliability) of a questionnaire / survey using multiple Likert questions that form a sale (Lund Research Ltd, 2013). The calculated Cronbach's alpha of the questionnaire (for Likert questions) was 0.715. The minimum requirement of calculated Cronbach's alpha of 0.70 (Field, 2009) was satisfied with respect to the present questionnaire. It has been reported that sufficient reliability and precision is achieved by using 3-4 questions (items) per scale (National Research Centre for the Working Environment, 2014). Therefore, three (03) questions were used per scale in the present feedback form **(Appendix XIII)**. The Cronbach's alpha of various scales / dimensions; the effectiveness of proposed interventions in mitigating existing risk factors (Cronbach's alpha: 0.917), capability of proposed interventions strategies in contributing to increased productivity (Cronbach's alpha : 0.957), contribution of proposed interventions strategies to worker's overall well-being (Cronbach's alpha: 0.946), imparting knowledge of ergonomics through the participatory process (Cronbach's alpha: 0.917), imparting decision making ability through participatory process (Cronbach's alpha : 0.885), implementation of proposed intervention strategies / recommendations (except shop-floor layout interventions) (Cronbach's alpha : 0.716), financial expenditure for implementing proposed intervention strategies / recommendations (except shop-floor layout interventions) (Cronbach's alpha: 0.926) satisfied the minimum requirement of calculated Cronbach's alpha of 0.70 (Field, 2009) with respect to the various scales in the present questionnaire.

The responses obtained from production managers / supervisors to the various dimensions in the feedback questionnaire were highly encouraging (table 8.1). The satisfaction of the production managers / supervisors in the injection-molded plastic furniture manufacturing industries with respect to the various design interventions was found to be good (table 8.1).

Table 8.1

Feedback from production managers / supervisors with regard to the proposed design interventions

Sl. No.	Dimensions	Response (%) (n = 13)				
		Strongly disagree	**Disagree**	**Undecided**	**Agree**	**Strongly agree**
1	Effectiveness of proposed interventions in mitigating existing risk factors	-	-	-	12.8	87.2
2	Capability of proposed intervention strategies in contributing to increased productivity	-	-	2.6	12.8	84.6
3	Contribution of proposed intervention strategies to worker's overall well-being	-	-	-	20.5	79.5
4	Imparting knowledge of ergonomics through participatory process	-	-	-	12.8	87.2
5	Imparting decision making ability through participatory process	-	-	7.7	15.4	76.9
		Very unlikely	**Unlikely**	**Undecided**	**Likely**	**Very likely**
6	Implementation of proposed intervention strategies / recommendations (except shop-floor layout interventions)	-	-	-	10.3	89.7
		Very high	**High**	**Undecided**	**Low**	**Very low**
7	Financial expenditure for implementing proposed intervention strategies / recommendations (except shop-floor layout interventions)				35.9	64.1
		Scores (% of response)				
8	Satisfaction level regarding design interventions	**00 -10** (0)	**11- 20** (0)	**21- 30** (0)	**31- 40** (0)	**41- 50** (0)
		51- 60 (0)	**61- 70** (0)	**71- 80** (7.7)	**81- 90** (38.5)	**91- 100** (53.8)

8.1.12 Limitations of the present research and future scope of work

- As day-long video recording was not permitted by factory managements computing the frequencies of individual working posture and its relative proportion (%) of working time was not possible. This limits measuring the amount of time spent in each posture. Studies incorporating day-long continuous videography for analysis of working posture may be attempted.

- Investigations pertaining to evaluation of indoor environmental parameters was aimed to investigate prevailing indoor work environment conditions and not for a detailed individual analysis of environmental variables (finding neutral temperatures, optimal thermal comfort parameters, etc.). Finding the optimum indoor environmental parameters found to be acceptable by the workers in the shop-floor may be investigated in the future.
- The effect of prevailing indoor environmental conditions on physical working capacity, stress, fatigue and human physiological mechanisms has not been assessed. The above mentioned aspects may be taken up for further study.
- Data logging devices which would have enabled day to day continuous measurements of different environmental variables (both during the night and daytime) were not used. Investigations using data logging devices for continuously monitoring indoor environmental parameters may be performed in future.
- Thermal sensation and thermal comfort votes were obtained from workers found working in workstations during data collection. Therefore some workers voted more than once (on different days) during investigations.
- Responses (related to thermal sensation and thermal comfort) were taken from males as females were not employed in shop-floor workstations.
- Shop-floor layout designs were investigated and suggestions proposed based on the indoor work environment based ergonomics perspective. Engineering considerations like man-machine utilization, the frequency of material movements, and production volumes were not taken into consideration.
- Shop-floor workstations concerned with manufacturing of other injection-molded plastic furniture products like table legs, baby chairs and table tops may be attempted in future.
- Investigations (using the research methodology adopted in present research work) may be extended for other manufacturing industries under MSMEs of India.

8.2 Conclusion

Present research work has established that ergonomics risk factors are prevalent in shop-floors of small and medium scale injection-molded plastic furniture manufacturing industries and such risk factors may be mitigated successfully with the help of suitable low cost design interventions. Low cost design interventions / strategies are practically feasible solutions for mitigating risk factors, as micro small and medium enterprises are intended to be labor intensive and have governmental restrictions on capital investment. The combination of research methods featuring questionnaire study, postural assessment tools, statistical analysis, direct observation, digital human modeling and work study technique was successful in identifying risk factors and in designing context specific validated design interventions.

The research methodology followed in present research work is perhaps first of its kind towards investigations from an ergonomics perspective in micro small and medium enterprises in India. Digital human modeling and simulation helped in evaluation of existing and proposed workstation designs and work methods without the construction of real physical prototypes and trials involving real human beings. Research methodology utilized in present research work may be easily adopted by researchers, production supervisors / managers / engineers towards implementing context specific ergonomic design solutions in the manufacturing sector shop-floor of industrially developing countries.

Business houses interested in expanding or establishing new injection-molded plastic furniture manufacturing factories in the small and medium sector will find the results of the current research endeavor highly beneficial. The innovative combination of research methodologies used in the present research endeavor may be replicated by initiating similar investigations in other sectors in order to identify industry specific problems for the purpose of and proposing and implementing contextual solutions.

8.2.1 Contribution of the present research work

The following are the notable contribution of the research work.

- Incorporation of physical, cognitive and environmental ergonomics in a particular research endeavor is perhaps the first of its kind with respect to ergonomics investigations in the Indian MSMEs. Real and virtual ergonomics evaluations were performed in present research work.

- Mediation statistics revealed that work shift duration significantly mediated the impact of workstation design and work posture for the occurrence of the symptoms of musculoskeletal ailments (figure 8.1).

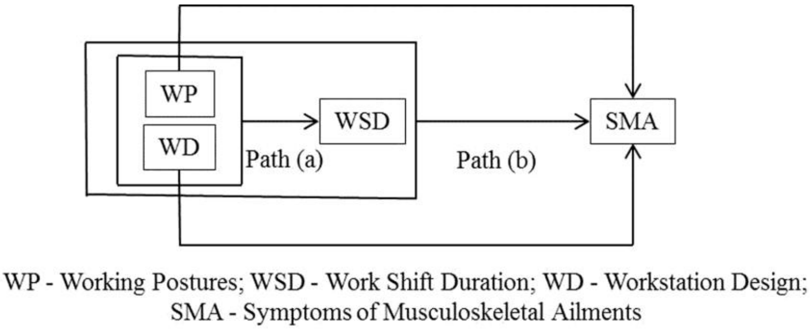


Fig 8.1 Inter-relationships and mediation model for work posture, workstation design and occurrence of the symptoms of musculoskeletal ailments

From mediation model, it is inferred that controlling WSD could be the solution towards reducing the occurrence of the symptoms of musculoskeletal ailments in the small and medium scale injection-molded plastic furniture manufacturing industries; if the scope for correcting poor workstation design, changing working postures and subsequent modification of work methods were limited / constrained by other factors. The proposed final ‘mediation model’ is perhaps the first of its kind in occupational health research (Sanjog et al., 2015 b)

- An innovative combination of research methodologies incorporating physical ergonomics, psychosocial work environment, subjective workload assessments, digital human modeling and simulation, work study, statistical modeling and indoor work environment was used to achieve the aim of the research work.
- Design guidelines were proposed for setting the shop-floor of the Indian small and medium scale injection-molded plastic furniture manufacturing industries from physical and environmental ergonomics viewpoint (Sanjog et al., 2015 c).

- Indoor environmental parameters were measured for one complete year for investigations, evaluations and proposing guidelines.
- A frame work (Appendix XIV) has been proposed (considering present research work) compiling all the methodologies adopted for identification of ergonomic risk factors and implementation of required design intervention to make the workstation human centric.
- The research work significantly contributes to the existing knowledge base of the industrial ergonomics investigations in the context of the industrially developing countries like India.

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10.0 Appendices

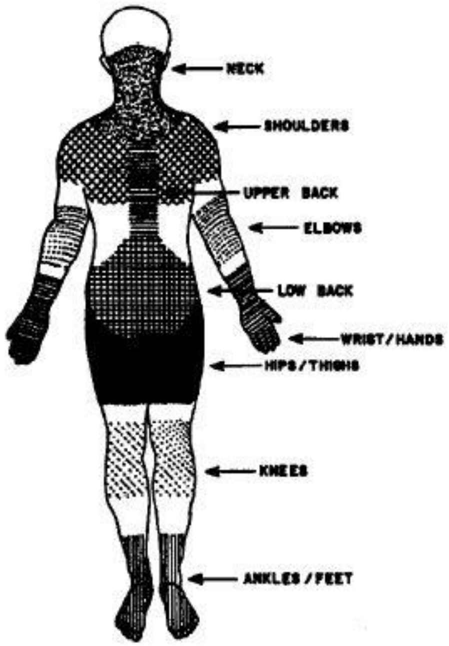
10.1 Appendix I

Standardized Nordic Questionnaire for Analysis of Musculoskeletal Symptoms (Kurnikova et al., 1986)

How to answer the questionnaire:

Please answer by putting a cross in the appropriate box—one cross for each question. You may be in doubt as to how to answer, but please do your best anyway. Please answer every question, even if you have never had trouble in any part of your body.

In this picture you can see the approximate position of the parts of the body referred to in the questionnaire. Limits are not sharply defined, and certain parts overlap. You should decide for yourself in which part you have or have had your trouble (if any).



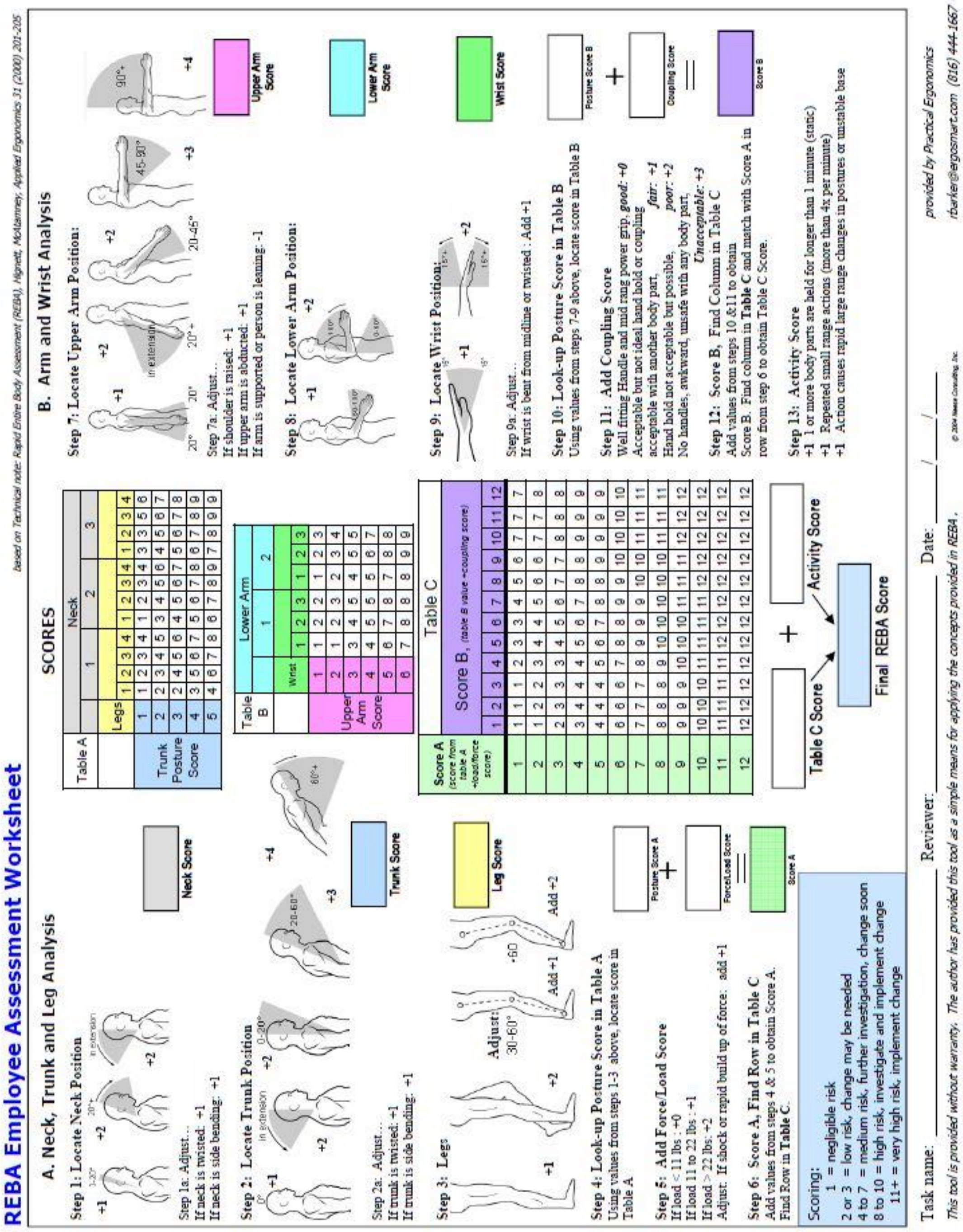
Trouble with the locomotive organs

	To be answered only by those who have had trouble	
Have you at any time during the last 12 months had trouble (ache, pain, discomfort) in:	Have you at any time during the last 12 months been prevented from doing your normal work (at home or away from home) because of the trouble?	Have you had trouble at any time during the last 7 days?
Neck 1 ☐ No 2 ☐ Yes	1 ☐ No 2 ☐ Yes	1 ☐ No 2 ☐ Yes
Shoulders 1 ☐ No 2 ☐, in the right shoulder 3 ☐ Yes, in the left shoulder 4 ☐ Yes, in both shoulders	1 ☐ No 2 ☐ Yes	1 ☐ No 2 ☐ Yes
Elbows 1 ☐ No 2 ☐ Yes, in the right elbow 3 ☐ Yes, in the left elbow 4 ☐ Yes, in both elbows	1 ☐ No 2 ☐ Yes	1 ☐ No 2 ☐ Yes
Wrists/hands 1 ☐ No 2 ☐ Yes, in the right wrist/hand 3 ☐ Yes, in the left wrist/hand 4 ☐ Yes, in both wrists/hands	1 ☐ No 2 ☐ Yes	1 ☐ No 2 ☐ Yes
Upper back 1 ☐ No 2 ☐ Yes	1 ☐ No 2 ☐ Yes	1 ☐ No 2 ☐ Yes
Low back (small of the back) 1 ☐ No 2 ☐	1 ☐ No 2 ☐ Yes	1 ☐ No 2 ☐ Yes
One or both hips/thighs 1 ☐ No 2 ☐	1 ☐ No 2 ☐ Yes	1 ☐ No 2 ☐ Yes
One or both knees 1 ☐ No 2 ☐	1 ☐ No 2 ☐ Yes	1 ☐ No 2 ☐ Yes
One or both ankles/feet 1 ☐ No 2 ☐	1 ☐ No 2 ☐ Yes	1 ☐ No 2 ☐ Yes

10.2 Appendix II

Rapid Entire Body Assessment

(based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205; provided by Practical Ergonomics, rbarker@ergosmart.com (816) 444-1667)



REBA Employee Assessment Worksheet

based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

+1 (0-20°) +2 (20°+) +2 (in extension)

Step 1a: Adjust…
If neck is twisted: +1
If neck is side bending: +1

Neck Score

Step 2: Locate Trunk Position

+1 (0°) +2 (in extension) +2 (0-20°) +3 (20-60°) +4 (60°+)

Step 2a: Adjust…
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 3: Legs

+1 +2 Adjust: 30-60° Add +1; 60 Add +2

Leg Score

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above, locate score in Table A

Posture Score A

Step 5: Add Force/Load Score
If load < 11 lbs : +0
If load 11 to 22 lbs : +1
If load > 22 lbs: +2
Adjust: If shock or rapid build up of force: add +1

Force/Load Score

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.

Score A

Scoring:
1 = negligible risk
2 or 3 = low risk, change may be needed
4 to 7 = medium risk, further investigation, change soon
8 to 10 = high risk, investigate and implement change
11+ = very high risk, implement change

SCORES

Table A	Neck	1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B	Lower Arm	1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table C

Score A (score from table A +load/force score)	Score B, (table B value +coupling score) 1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + Activity Score → Final REBA Score

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

+1 (20° 20°) +2 (in extension) +2 (20°+) +2 (20-45°) +3 (45-90°) +4 (90°+)

Step 7a: Adjust…
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 8: Locate Lower Arm Position:

+1 (60-100°) +2 (100°+; 0-60°)

Lower Arm Score

Step 9: Locate Wrist Position:

+1 (15°) +2 (15°+)

Step 9a: Adjust…
If wrist is bent from midline or twisted : Add +1

Wrist Score

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B

Posture Score B

Step 11: Add Coupling Score
Well fitting Handle and mid rang power grip, *good: +0*
Acceptable but not ideal hand hold or coupling acceptable with another body part, *fair: +1*
Hand hold not acceptable but possible, *poor: +2*
No handles, awkward, unsafe with any body part, *Unacceptable: +3*

Coupling Score

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain Score B. Find column in **Table C** and match with Score A in row from step 6 to obtain Table C Score.

Score B

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Task name: ______________ Reviewer: ______________ Date: ___/___/___

This tool is provided without warranty. The author has provided this tool as a simple means for applying the concepts provided in REBA.

provided by Practical Ergonomics rbarker@ergosmart.com (816) 444-1667

10.3 Appendix III

Ovako Working Posture Analysis System

Definition of four codes for the back postures in the OWAS systems

1	Back straight	"Back straight" means that worker's back is less than 20º (the angle of the lines which go between head-hips and legs) bent forward or sideways or less than 20º twisted (the angle between shoulders and hips.
2	Back bent	"Back bent" means that worker is in a posture which the upper body is bent forward or backward 20º (the angle of the lines which go between head-hips and legs) or more.
3	Back twisted (or bent sideways)	"Back twisted" means that the back is twisted 20º or more (as defined above) or bent sideways 20º or more.
4	Back bent and twisted	"Back bent and twisted" means a situation where back (like in case 2) and simultaneously twisted (like in case 3).

(adopted from Mattila and Vilkki, 1998)

Definition of three codes for the arm postures in the OWAS method

1	Both arms below shoulder level	"Both arms below shoulder level" means a situation in which both arms are completely below shoulder level.
2	One arm at or above shoulder level	"One arm at or above shoulder level" means that one arm or part of it is at or above shoulder level.
3	Both arms at or above shoulder level	In "Both arms at or above shoulder level" both arms are fully or partially at or above shoulder level.

(adopted from Mattila and Vilkki, 1998)

Definition of the seven postures for legs in the OWAS method

1	Sitting	"Sitting" means that the weight of the body is supported on the buttocks. In this posture the legs are also below the buttocks.
2	Standing on both straight legs	"Standing on both straight legs" means that the weight of the body is supported on two straight legs. The knee angle is more than 150º.
3	Standing on one straight leg	"Standing on one straight leg" is a situation in which one leg is straight and the weight of the body is completely supported by that leg. The knee angle is more than 150º.
4	Standing or squatting on both feet, knees bent	In this posture the weight of the body is on both legs and both knees are bent on a 150º or smaller angle.
5	Standing or squatting on one foot, knee bent	In this posture the weight of the body is on one leg, and is also bent from the knee. The knee angle is 150º or smaller.
6	Kneeling on one or both knees	In this posture the person is kneeling either on both knees or one knee.
7	Walking or moving	In this posture the person is walking or moving around at the work place.

(adopted from Mattila and Vilkki, 1998)

Definition of three codes for the load handled in the OWAS method

1	Load/use of force ≤ 10 KG	Weight handled or force needed is 10 kg or less.
2	Load/use of force > 10 kg ≤ 20 KG	Weight handled or force needed exceeds 10 kg but less than 20 kg.
3	Load/use of force > 20 KG	Weight handled or force needed exceeds 20 kg

(adopted from Mattila and Vilkki, 1998)

The OWAS action categories for prevention

Action Category	Explanation
1	Normal and natural postures with no harmful effect on the musculoskeletal system – No action required
2	Posture with some harmful effect on the musculoskeletal system – Corrective actions required in the near future
3	Posture have a harmful effect on the musculoskeletal system – Corrective actions should be done as soon as possible
4	The load caused by these postures has a very harmful effect on the musculoskeletal system – Corrective actions for improvement required immediately

(adopted from Mattila and Vilkki, 1998)

Action category for each individual OWAS classified posture combination

back	arms	1			2			3			4			5			6			7			legs
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	Use of force
1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	
	2	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1	
	3	1	1	1	1	1	1	1	1	1	2	2	3	2	2	3	1	1	1	1	1	2	
2	1	2	2	3	2	2	3	2	2	3	3	3	3	3	3	3	2	2	2	2	3	3	
	2	2	2	3	2	2	3	2	3	3	3	4	4	3	4	4	3	3	4	2	3	4	
	3	3	3	4	2	2	3	3	3	3	3	4	4	4	4	4	3	3	4	2	3	4	
3	1	1	1	1	1	1	1	1	1	2	3	3	3	4	4	4	1	1	1	1	1	1	
	2	2	2	3	1	1	1	1	1	2	4	4	4	4	4	4	3	3	3	1	1	1	
	3	2	2	3	1	1	1	2	3	3	4	4	4	4	4	4	4	4	4	1	1	1	
4	1	2	3	3	2	2	3	2	2	3	4	4	4	4	4	4	4	4	4	2	3	4	
	2	3	3	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4	
	3	4	4	4	2	3	4	3	3	4	4	4	4	4	4	4	4	4	4	2	3	4	

(adopted from Mattila and Vilkki, 1998)

10.4 Appendix IV

Personal Information Questionnaire

(adopted and modified from Ostrom, 1993; Engels et al., 1996; Chiu et al., 2002; Choobineh et al., 2004; Bhattacharyya, 2011)

Name :		
Age : Department :	Gender : Male / Female	
Height :	Weight :	Native state :
Dominant hand : left ( ) right ( )		
Do you wear corrective lenses, if yes what kind?		
Type of job :		Daily working hours:
Do you exercise regularly (eg. Walk, jog at least 3 times a week Yes ( ) No ( )		
Have you received any formal training on ergonomics at your workplace Yes ( ) No ( )		
Year of joining the present job :		
Did you discontinue your job between these years:		
Type of family : joint/ nuclear/ extended		
No. of family members:		
Do you smoke : Yes / No		
Do you consume alcohol : Yes / No		
Do you chew tobacco : Yes / No		
Do you use any of these at you home	Fan ( ) Air conditioning ( ) Cooler ( ) None of the above ( )	
Type of sitting posture adopted at home	Use chair for sitting ( ) Cross legged on floor ( ) Alternate between these two ( ) Any other mode of sitting, mention details	
Type of sitting posture adopted at work	Use chair for sitting ( ) Cross legged on floor ( ) Alternate between these two ( ) Any other mode of sitting, mention details	
Do you use any of these at you work	Fan ( ) Air conditioning ( ) Cooler ( ) None of the above ( )	

Highest Educational qualification Languages known Assamese Read ( ) Write ( ) Speak ( ) English Read ( ) Write ( ) Speak ( ) Hindi Read ( ) Write ( ) Speak ( )
State any medical problems diagnosed by the physician
Are you under any medication at present
Have you been ever told by a physician that you have/had any of the following medical illness ? Diabetes : Yes / No Hypothyroidism/underactive thyroid : Yes / No Ruptured disc in the neck : Yes / No Ruptured disc in the back : Yes / No Rheumatoid arthritis : Yes / No Carpel tunnel syndrome : Yes / No

10.5 Appendix V

Personal information details of shop-floor workers

Sl. No	Parameters	Descriptive statistics	Particulars / units	Department / Workstation: Blending / Mixing (n = 29)	Granulator / Grinding (n = 10)	Injection-Molding (n = 46)
1	Age	M ± SD	Years	26.7 ± 4.3	27.1 ± 2.5	25.1 ± 3.3
2	Weight	M ± SD	kilograms	56.1 ± 7.7	61.6 ± 2.9	57.9 ± 7.1
3	Stature	M ± SD	centimeters	159.4 ± 18.9	164.7 ± 6.1	165.5 ± 6.3
4	Experience	M ± SD	Years	2.1 ± 0.9	2.0 ± 0.8	2.3 ± 1.3
5	Discontinuity in present employment	%	Yes	--	--	--
			No	100	100	100
6	Native state	%	Assam	100	100	100
			Other states	--	--	--
7	Dominant hand	%	Left handed	3.44	10	0
			Right handed	96.56	90	100
8	Eye – corrective lens	%	Yes	6.90	0	4.35
			No	93.10	100	95.65
9	Working hours	%	8 hours	--	--	8.7
			12 hours	100	100	91.3
10	Exercise	%	Yes	31.03	30	21.74
			No	68.97	70	78.26
11	Formal training in ergonomics at workplace	%	Yes	--	--	--
			No	100	100	100
12	Educational status	%	No formal education	6.90	10	2.17
			Class 4	--	10	--
			Class 6	3.45	--	
			Class 7	6.90	--	4.35
			Class 8	34.48	--	8.70
			Class 9	13.97	60	17.39
			Class 10	24.14	20	30.43
			Class 11	3.45	--	2.17
			Class 12	6.90	--	23.91
			Graduation	--	--	2.17
			ITI	--	--	4.35
			Diploma	--	--	4.35
13	Type of family	%	Joint	51.72	50	52.17
			Nuclear	44.83	50	47.83
			Extended	3.45	00	0
14	Staying without family at company provided accommodation	%	Yes	41.39	10	47.83
			No	58.61	90	52.17
15	Addiction	%	Smoking	27.59	40	34.78
			Alcohol	58.61	80	56.52
			Chewing tobacco	51.72	80	43.48
16	Access to physical environmental comfort at home	%	Fan	55.17	80	58.70
			Air conditioner	0	0	0
			Air cooler	0	0	0

			None of the above	44.83	20	41.30
17	Access to physical environmental comfort at workplace	%	Fan	0	100	100
			Air conditioner	0	0	0
			Air cooler	0	0	0
			None of the above	100	0	0
18	Sitting behavior at home	%	Chair	17.24	10	17.39
			Cross legged on floor / bed	44.83	30	45.65
			Alternate between chair and Cross legged on floor / bed	37.93	60	36.96
19	Sitting behavior at work place	%	Chair	65.58	80	84.78
			Cross legged on floor / bed	0	0	0
			Alternate between chair and Cross legged on floor / bed / others	34.42	20	15.22
20	Language proficiency Assamese	%	Read	93.10	80	97.83
			Write	89.65	80	97.83
			Speak	100	100	100
21	Language proficiency Hindi	%	Read	65.52	70	73.91
			Write	65.52	40	69.57
			Speak	100	90	93.48
22	Language proficiency English	%	Read	6.90	0	19.57
			Write	3.45	0	13.04
			Speak	3.45	0	93.48
23	Medical status – Medical problems diagnosed by the physician	%	Yes	6.90	10	23.91
			No	93.10	90	76.09
24	Under medication	%	Yes	0	0	8.70
			No	100	100	91.30
24	Type of medical problems	--	--	gastric	gastric	gastric, head ache
26	Diagnosed with					
	Diabetes	%	Yes	--	--	--
			No	100	100	100
	Hypo / Hyper thyroid		Yes	--	--	--
			No	100	100	100
	Ruptured disc in the neck		Yes	--	--	--
			No	100	100	100
	Ruptured disc in the back		Yes	--	--	--
			No	100	100	100

Rheumatoid arthritis	Yes	--	--	--
	No	100	100	100
Carpel tunnel syndrome	Yes	--	--	--
	No	100	100	100

Legends: M ± SD – Mean ± Standard Deviation; % - Percentage

10.6 Appendix - VI

Copenhagen Psychosocial Questionnaire II Medium Version Questionnaire for assessment of psychosocial work Environment

(The Copenhagen Psychosocial Questionnaire II - medium version)
(Available from: http://www.arbejdsmiljoforskning.dk/~/media/Spoergeskemaer/copsoq/uk/copsoq-ii-medium-size-questionnaire-english.pdf#. [Accessed 21 August 2013])

The following questions are about your psychosocial work environment and job satisfaction. Some of the questions may fit better to your work than others, but please answer all questions.

	Always	Often	Some-times	Seldom	Never/ hardly ever
Is your work unevenly distributed so it piles up?	☐	☐	☐	☐	☐
Does your work put you in emotionally disturbing situations?	☐	☐	☐	☐	☐
Do you have a large degree of influence concerning your work?	☐	☐	☐	☐	☐
Do you have to work very fast?	☐	☐	☐	☐	☐
Is there a good atmosphere between you and your colleagues?	☐	☐	☐	☐	☐
Do you have to relate to other people's personal problems as part of your work?	☐	☐	☐	☐	☐
Do you have a say in choosing who you work with?	☐	☐	☐	☐	☐
Do you have any influence on what you do at work?	☐	☐	☐	☐	☐
Do you get behind with your work?	☐	☐	☐	☐	☐
Is there good co-operation between the colleagues at work?	☐	☐	☐	☐	☐
How often do you not have time to complete all your work tasks?	☐	☐	☐	☐	☐
Do you have enough time for your work tasks?	☐	☐	☐	☐	☐

	Always	Often	Some-times	Seldom	Never/ hardly ever
Do you feel part of a community at your place of work?	☐	☐	☐	☐	☐
Can you influence the amount of work assigned to you?	☐	☐	☐	☐	☐
How often do you consider looking for work elsewhere?	☐	☐	☐	☐	☐
How often do you get help and support from your colleagues?	☐	☐	☐	☐	☐
How often are your colleagues willing to listen to your problems at work?	☐	☐	☐	☐	☐
How often do your colleagues talk with you about how well you carry out your work?	☐	☐	☐	☐	☐

	To a very large extent	To a large extent	Some-what	To a small extent	To a very Small extent
Is it necessary to keep working at a high pace?	☐	☐	☐	☐	☐
Is your work emotionally demanding?	☐	☐	☐	☐	☐
Does your work require you to take the initiative?	☐	☐	☐	☐	☐
Is your work meaningful?	☐	☐	☐	☐	☐
At your place of work, are you informed well in advance concerning for example important decisions, changes, or plans for the future?	☐	☐	☐	☐	☐
Does your work have clear objectives?	☐	☐	☐	☐	☐

	To a very large extent	To a large extent	Some-what	To a small extent	To a very Small extent
Are contradictory demands placed on you at work?	☐	☐	☐	☐	☐
Is your work recognised and appreciated by the management?	☐	☐	☐	☐	☐
Do you feel that the work you do is important?	☐	☐	☐	☐	☐
Would you recommend a good friend to apply for a position at your workplace?	☐	☐	☐	☐	☐
Do you know exactly which areas are your responsibility ?	☐	☐	☐	☐	☐
Does the management at your workplace respect you?	☐	☐	☐	☐	☐
Do you get emotionally involved in your work?	☐	☐	☐	☐	☐
Can you use your skills or expertise in your work?	☐	☐	☐	☐	☐
Do you enjoy telling others about your place of work?	☐	☐	☐	☐	☐
Do you receive all the information you need in order to do your work well?	☐	☐	☐	☐	☐
Do you do things at work, which are accepted by some people but not by others?	☐	☐	☐	☐	☐
Are you treated fairly at your workplace?	☐	☐	☐	☐	☐
Do you know exactly what is expected of you at work?	☐	☐	☐	☐	☐
Do you sometimes have to do things, which ought to have been done in a different way?	☐	☐	☐	☐	☐

Do you have the possibility of learning new things through your work? ☐ ☐ ☐ ☐ ☐

	To a very large extent	To a large extent	Some-what	To a small extent	To a very Small extent
Do you feel motivated and involved in your work?	☐	☐	☐	☐	☐
Do you sometimes have to do things, which seem to be unnecessary?	☐	☐	☐	☐	☐
Do you work at a high pace throughout the day?	☐	☐	☐	☐	☐
Does your work give you the opportunity to develop your skills?	☐	☐	☐	☐	☐
Do you feel that your place of work is of great importance to you?	☐	☐	☐	☐	☐

Regarding your work in general.
How pleased are you with:

	Very satisfied	Satisfied	Un-satisfied	Very Un-satisfied
- your work prospects?	☐	☐	☐	☐
- the physical working conditions?	☐	☐	☐	☐
- the way your abilities are used?	☐	☐	☐	☐
- your job as a whole, everything taken into consideration?	☐	☐	☐	☐

The workplace as a whole

The next questions are not about your own job but about the workplace as a whole.

	To a very large extent	To a large extent	Some-what	To a small extent	To a very Small extent
Does the management trust the employees to do their work well?	☐	☐	☐	☐	☐
Can you trust the information that comes from the management?	☐	☐	☐	☐	☐
Are conflicts resolved in a fair way?	☐	☐	☐	☐	☐
Does the management withhold important information from the employees?	☐	☐	☐	☐	☐
Are employees appreciated when they have done a good job?	☐	☐	☐	☐	☐
Do the employees withhold information from each other?	☐	☐	☐	☐	☐
Do the employees withhold information from the management?	☐	☐	☐	☐	☐
Do the employees in general trust each other?	☐	☐	☐	☐	☐
Are all suggestions from employees treated seriously by the management?	☐	☐	☐	☐	☐
Are the employees able to express their views and feelings?	☐	☐	☐	☐	☐
Is the work distributed fairly?	☐	☐	☐	☐	☐

The next questions concern your relationship to your nearest superior.

	Always	Often	Some-times	Seldom	Never/ hardly ever
How often is your nearest superior willing to listen to your problems at work?	☐	☐	☐	☐	☐

How often do you get help and support from your nearest superior?	☐	☐	☐	☐	☐
How often does your nearest superior talk with you about how well you carry out your work?	☐	☐	☐	☐	☐

To what extent would you say that your immediate superior...

	To a very large extent	To a large extent	Some-what	To a small extent	To a very Small extent
- makes sure that the individual member of staff has good development opportunities?	☐	☐	☐	☐	☐
- gives high priority to job satisfaction?	☐	☐	☐	☐	☐
- is good at work planning?	☐	☐	☐	☐	☐
- is good at solving conflicts?	☐	☐	☐	☐	☐

Work and private life

The next questions are about the connection between work and private life.

	Yes, Often	Yes, some times	Rarely	No, never
Do you often feel a conflict between your work and your private life, making you want to be in both places at the same time?	☐	☐	☐	☐

	Yes, certainly	Yes, to a certain degree	Yes, but only very little	No, not at all
Do you feel that your work drains so much of your energy that it has a negative effect on your private life?	☐	☐	☐	☐
time that it has a negative effect on your private life?	☐	☐	☐	☐
Do your friends or family tell you that you work too much?	☐	☐	☐	☐

If you have more comments on your psychosocial work environment, please write here

---

Health and well-being

These questions are about how you have been during the last 4 weeks.

	All the time	A large part of the time	Part of the time	A small part of the time	Not at all
How often have you slept badly and restlessly?	☐	☐	☐	☐	☐
How often have you felt worn out?	☐	☐	☐	☐	☐
How often have you found it hard to go to sleep?	☐	☐	☐	☐	☐
How often have you been physically exhausted?	☐	☐	☐	☐	☐

How often have you been emotionally exhausted?	☐	☐	☐	☐	☐
How often have you woken up too early and not been able to get back to sleep?	☐	☐	☐	☐	☐
How often have you felt tired?	☐	☐	☐	☐	☐
How often have you woken up several times and found it difficult to get back to sleep?	☐	☐	☐	☐	☐
How often have you had problems relaxing?	☐	☐	☐	☐	☐
How often have you been irritable?	☐	☐	☐	☐	☐
How often have you been tense?	☐	☐	☐	☐	☐
How often have you been stressed?	☐	☐	☐	☐	☐

	Excellent	Very good	Good	Fair	Poor
In general, would you say your health is:	☐	☐	☐	☐	☐

Conflicts and offensive behaviours

	Yes, daily	Yes, weekly	Yes, monthly	Yes, a few times	No
Have you been exposed to undesired sexual attention at your workplace during the last 12 months?	☐	☐	☐	☐	☐

	Colleagues	Manager/ Superior	Sub ordinates	Clients/ Customers/ Patients
If yes, from whom? (You may tick off more than one)	☐	☐	☐	☐

Yes, daily	Yes, weekly	Yes, monthly	Yes, a few times	No

Have you been exposed to threats of violence at your workplace during the last 12 months? ☐ ☐ ☐ ☐ ☐

Colleagues	Manager/ Superior	Sub ordinates	Clients/ Customers/ Patients

If yes, from whom? (You may tick off more than one) ☐ ☐ ☐ ☐

Yes, daily	Yes, weekly	Yes, monthly	Yes, a few times	No

Have you been exposed to physical violence at your workplace during the last 12 months? ☐ ☐ ☐ ☐ ☐

Colleagues	Manager/ Superior	Sub ordinates	Clients/ Customers/ Patients

If yes, from whom? (You may tick off more than one) ☐ ☐ ☐ ☐

Bullying means that a person repeatedly is exposed to unpleasant or degrading treatment, and that the person finds it difficult to defend himself or herself against it.

Yes, daily	Yes, weekly	Yes, monthly	Yes, a few times	No

Have you been exposed to bullying at your workplace during the last 12 months? ☐ ☐ ☐ ☐ ☐

Colleagues	Manager/ Superior	Sub ordinates	Clients/ Customers/ Patients

If yes, from whom? (You may tick off more than one) ☐ ☐ ☐ ☐

There are no further questions.

Thank you for filling out the questionnaire.

10.7 Appendix VII

NASA TLX - Sources of workload comparison charts

(Miller, 2001)

Effort or Performance	Temporal Demand or Frustration
Temporal Demand or Effort	Physical Demand or Frustration
Performance or Frustration	Physical Demand or Temporal Demand
Physical Demand or Performance	Temporal Demand or Mental Demand
Frustration or Effort	Performance or Mental Demand
Performance or Temporal Demand	Mental Demand or Effort
Mental Demand or Physical Demand	Effort or Physical Demand
Frustration or Mental Demand	

10.8 Appendix VIII

NASA TLX - Rating Scale Definitions

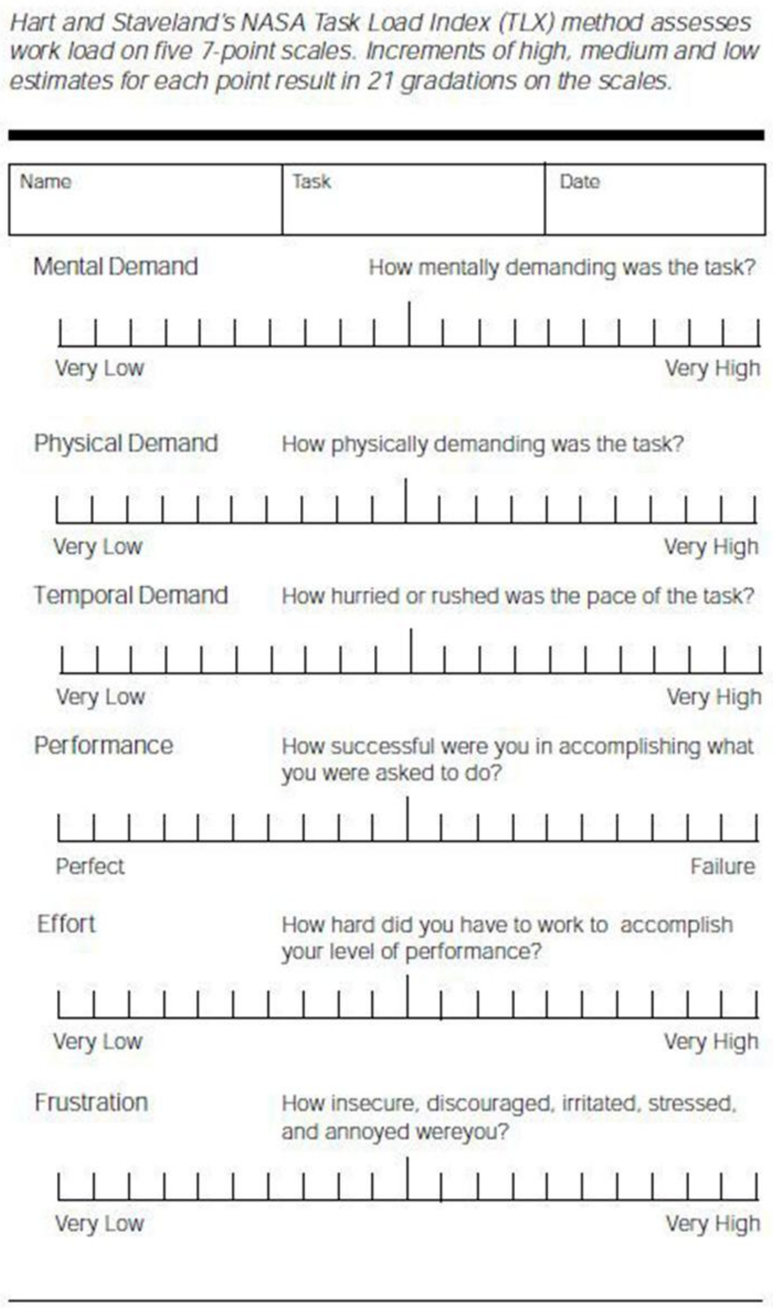
(Hart & Staveland, 1988)

Title	End Points	Descriptions
Mental Demand	Low/High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting, or forgiving?
Physical Demand	Low/High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

10.9 Appendix IX

NASA Task Load Index (TLX) Scale

(adopted from https://en.wikipedia.org/wiki/NASA-TLX#/media/File:NasaTLX.png)



Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

10.10 Appendix X

The Bedford and ASHRAE seven-point scales

(adopted from Deb and Ramachandraiah, 2010)

Bedford scale		ASHRAE scale	
Much too warm	3	Hot	3
Too warm	2	Warm	2
Comfortably warm	1	Slightly warm	1
Comfortable	0	Neutral	0
Comfortably cool	-1	Slightly cool	-1
Too cool	-2	Cool	-2
Much too cool	-3	Cold	-3

10.11 Appendix XI

Questionnaire for evaluation of thermal perception

(adopted and modified from Deb and Ramachandraiah, 2010)

Date	Current Time	Wind speed	Max. 3 sec. gust	Average Wind speed	Dry bulb temperature (˚C)	Wet bulb Temperature (˚C)	Wind chill	Relative humidity	Heat Index	Dew point (˚C)	Globe Temperature (˚C)	Illuminance (lux)

Name	:
Age	:
Gender	:
Clothing	:
Are you under a fan	: Yes / No / partially

Thermal sensation

Cold [ ] Cool Slightly [ ] Cool [ ] Neutral [ ] Slightly warm [ ] Warm [ ] Hot [ ]

Feeling of comfort

Much too cold [ ] Too cool [ ] Comfortably cool [ ] Comfortable [ ] Comfortably warm [ ] Too warm [ ] Much too warm [ ]

Level of Air movement should be

Lesser [ ] As it is [ ] More [ ]

Level of Humidity should be

Lesser [ ] As it is [ ] More [ ]

How would you like to be?

Cooler [ ] As it is [ ] Warmer [ ]

Are the overall conditions acceptable

Yes [ ] No [ ]

10.12 Appendix XII

Feedback form for production managers / supervisors

(adopted and modified from Hendrick, 1996; Haims and Carayon, 1998; Loisel et al., 201; Laing et al., 2005; Morel et al., 2009; Wu et al., 2010)

Please give your opinions on the proposed design interventions based on ergonomics perspectives

1. Proposed intervention strategies show significant improvement when compared with the existing / prevailing conditions.

(1)	(2)	(3)	(4)	(5)
Strongly disagree	Disagree	Undecided	Agree	Strongly agree

2. Proposed design interventions are capable of contributing to increased productivity.

(1)	(2)	(3)	(4)	(5)
Strongly disagree	Disagree	Undecided	Agree	Strongly agree

3. Proposed design interventions are capable of contributing to increased safety, health, comfort and quality of work life of the workers.

(1)	(2)	(3)	(4)	(5)
Strongly disagree	Disagree	Undecided	Agree	Strongly agree

4. The participatory process contributed to your level of learning and knowledge.

   (a) in ergonomics.

(1)	(2)	(3)	(4)	(5)
Strongly disagree	Disagree	Undecided	Agree	Strongly agree

   (b) in your ability to make decisions and implement changes.

(1)	(2)	(3)	(4)	(5)
Strongly disagree	Disagree	Undecided	Agree	Strongly agree

5. Scope for implementation of proposed ergonomic solutions in present factories (excluding shop-floor layout interventions).

(1)	(2)	(3)	(4)	(5)
Very unlikely	unlikely	Undecided	Likely	Very likely

6. Financial expenditure for implementing proposed ergonomic interventions (except Shop-floor layout interventions)

(1)	(2)	(3)	(4)	(5)
Very high	High	Unable to judge	Less	Very less

7. Raise in productivity can be achieved with the help of proposed design interventions.

(1)	(2)	(3)	(4)	(5)
Strongly disagree	Disagree	Undecided	Agree	Strongly agree

8.

(a) Increase in your knowledge and education through information sharing process in understanding the science of interaction between man, machine and surrounding environment.

(1)	(2)	(3)	(4)	(5)
Strongly disagree	Disagree	Undecided	Agree	Strongly agree

(b) Increase in your knowledge and education through information sharing process for advising modifications in work place.

(1)	(2)	(3)	(4)	(5)
Strongly disagree	Disagree	Undecided	Agree	Strongly agree

9. Suggested intervention strategies are helpful for mitigating risk factors in existing / prevailing conditions.

(1)	(2)	(3)	(4)	(5)
Strongly disagree	Disagree	Undecided	Agree	Strongly agree

10. The possibility of realizing recommended ergonomic solutions in present factories.

(1)	(2)	(3)	(4)	(5)
Very unlikely	unlikely	Undecided	Likely	Very likely

11. Occupational work environment can be positively improved with the help of proposed design interventions.

(1)	(2)	(3)	(4)	(5)
Strongly disagree	Disagree	Undecided	Agree	Strongly agree

12. Expected cost outlay for implementing proposed ergonomic interventions.

(1)	(2)	(3)	(4)	(5)
Very high	High	Unable to judge	Less	Very less

13. Can expect a positive response regarding implementation of research proposals in present factories.

(1)	(2)	(3)	(4)	(5)
Very unlikely	unlikely	Undecided	Likely	Very likely

14. Ergonomic risk factors in shop-floor workstation may be reduced / eliminated with the implementation of research outcomes.

(1)	(2)	(3)	(4)	(5)
Strongly disagree	Disagree	Undecided	Agree	Strongly agree

15. Financial burden on the factories for implementing research proposals.

(1)	(2)	(3)	(4)	(5)
Very high	High	Unable to judge	Less	Very less

16. There is sure possibility of increase in productivity if research proposals are implemented.

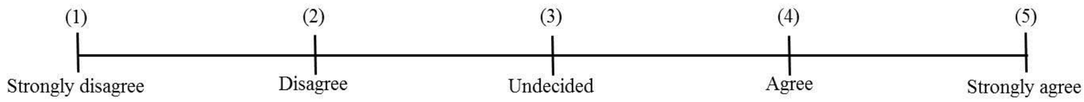
(1)	(2)	(3)	(4)	(5)
Strongly disagree	Disagree	Undecided	Agree	Strongly agree

17. Likelihood of betterment of worker's occupational well-being if research proposals are implemented.

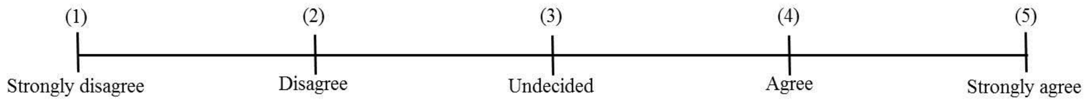
(1)	(2)	(3)	(4)	(5)
Strongly disagree	Disagree	Undecided	Agree	Strongly agree

18.

(a) Association with the research endeavor resulted in developing sufficient know- how in user-centered work place design.



(b) Association with the research endeavor resulted in developing sufficient know- how in your ability to identify risk factors and design modifications.



19. Which grade can represent your satisfaction level about the proposed intervention strategies?

□ 0 -10 □ 11- 20 □ 21- 30 □ 31- 40 □ 41- 50 □ 51- 60 □ 61- 70 □ 71- 80 □ 81- 90 □ 91- 100

10.13 Appendix XIII

The scales of the feedback form for production managers / supervisors

1. Effectiveness of proposed interventions in mitigating existing risk factors (Cronbach's alpha 0.917)

   Q1. Proposed intervention strategies show significant improvement when compared with the existing / prevailing conditions.

   Q9. Suggested intervention strategies are helpful for mitigating risk factors in existing / prevailing conditions.

   Q14. Ergonomic risk factors in shop-floor workstation may be reduced / eliminated with the implementation of research outcomes.

2. Capability of proposed intervention strategies in contributing to increased productivity (Cronbach's alpha 0.957)

   Q2. Proposed design interventions are capable of contributing to increased productivity.

   Q7. Raise in productivity can be achieved with the help of proposed design interventions.

   Q16. There is sure possibility of increase in productivity if research proposals are implemented.

3. Contribution of proposed intervention strategies to worker's overall well-being (Cronbach's alpha 0.946)

   Q3. Proposed design interventions are capable of contributing to increased safety, health, comfort and quality of work life of the workers.

   Q11. Occupational work environment can be positively improved with the help of proposed design interventions.

   Q17. Likelihood of betterment of worker's occupational well-being if research proposals are implemented.

4. Imparting knowledge of ergonomics through participatory process (Cronbach's alpha 0.917)

   Q4a. The participatory process contributed to your level of learning and knowledge in ergonomics.

   Q8a. Increase in your knowledge and education through information sharing process in understanding the science of interaction between man, machine and surrounding environment.

Q18a. Association with the research endeavor resulted in developing sufficient know- how in user-centered work place design.

5. Imparting decision making ability through participatory process (Cronbach's alpha 0.885)

Q4b. The participatory process contributed to your level of learning and knowledge in your ability to make decisions and implement changes.

Q8b. Increase in your knowledge and education through information sharing process for advising modifications in work place.

Q18b. Association with the research endeavor resulted in developing sufficient know-how in your ability to identify risk factors and design modifications.

6. Implementation of proposed intervention strategies / recommendations (except shop-floor layout interventions) (Cronbach's alpha 0.716)

Q5. There is good scope for implementation of proposed ergonomic solutions in present factories.

Q10. The possibility of realizing recommended ergonomic solutions in present factories.

Q13. Can expect a positive response regarding implementation of research proposals in present factories.

7. Financial expenditure for implementing proposed intervention strategies/recommendations (except shop-floor layout interventions). (Cronbach's alpha 0.926)

Q6. Financial expenditure likely for implementing proposed ergonomic interventions.

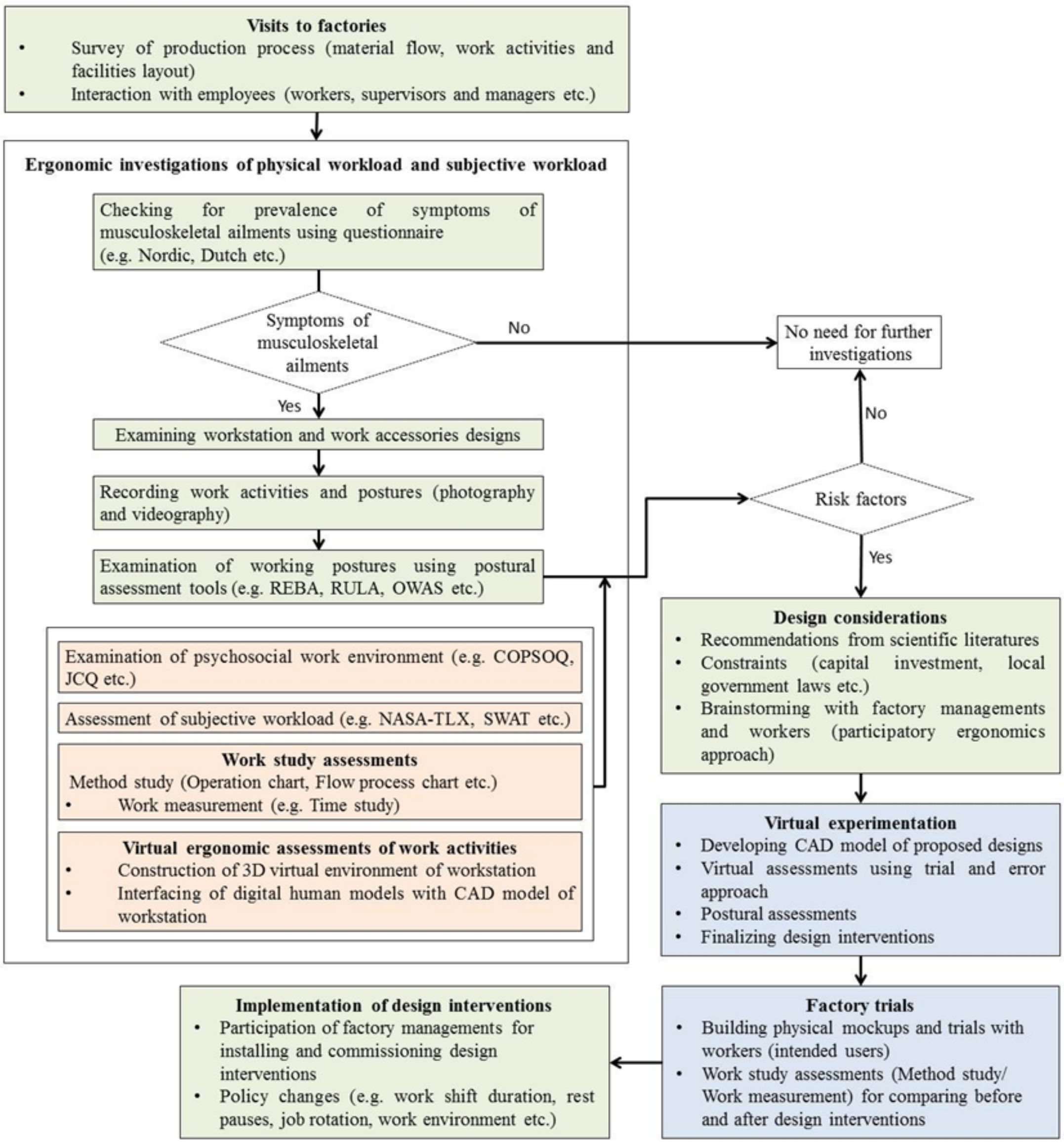
Q12. Expected cost outlay for implementing proposed ergonomic interventions.

Q15. Financial burden on the factories for implementing research proposals.

10.14 Appendix XIV

Framework for identification of ergonomic risk factors and implementation of required design intervention to make the workstation human centric

(adopted from sanjog et al., 2016)



REBA : Rapid Entire Body Assessment; RULA : Rapid Upper Limb Assessment; OWAS : Ovako Working Posture Assessment System; COPSOQ : Copenhagen Psychosocial Questionnaire; JCQ : Job Content Questionnaire; NASA – TLX : The National Aeronautics and Space Administration Task Load Index; SWAT : Subjective workload Assessment Techniques

10.15 Appendix XV

Publications

Publications in reviewed scientific journal

1. **Sanjog, J.,** Patnaik, B., Patel, T., Karmakar, S. (2016). Context-specific design interventions in blending workstation: an ergonomics perspective. *Journal of Industrial and Production Engineering*. 31 (1), 32-50. [Taylor & Francis]
2. **Sanjog, J.,** Patel, T., Chowdhury, A., and Karmakar, S. (2015). Musculoskeletal ailments in Indian injection-molded plastic furniture manufacturing shop-floor: Mediating role of work shift duration. *International Journal of Industrial Ergonomics*, 48, 89-98. [Elsevier]
3. Karmakar, S., **Sanjog, J.,** and Patel, T. (2014). Digital Human Modeling and Simulation in Product and Workplace Design: Indian Scenario. *International Journal of Engineering Research and Applications*, Special Issue. pp. 06 -12. [ISSN: 2248-9622]
4. **Sanjog, J.,** Patel, T., and Karmakar, S. (2013). Indoor physical work environment: an ergonomics perspective. *International Journal of Science, Engineering and Technology Research*, 2 (3), 507-513. [ISSN: 2278-7798]
5. **Sanjog, J.,** Karmakar, S., Patel, T., and Chowdhury, A. (2012). DHM an aid for virtual ergonomics of manufacturing shop-floor: A review with reference to industrially developing countries. *International Journal of Computer Applications*, 54 (14), 18-23. [ISSN: 0975 - 8887]

Publications in conference proceedings

1. **Sanjog, J.,** Dash, T., Patel, T., Karmakar, S., (2015). Redesign of small and medium scale injection-molded plastic furniture manufacturing shop-floor: Physical and environmental ergonomics aspects. In: Proceedings of 8th International Conference on Planning and Design (ICPD), National Cheng Kung University, Tainan, Taiwan, 25th – 28th May, C-101. [ISBN: 978-986-04-4432-2]
2. **Sanjog, J.,** Patel, T., and Karmakar, S. (2014). Reduction of hand grip strength as an indicator towards discomfort of upper body extremities, In:

Proceedings of International Ergonomics Conference, HWWE-2014, (12th ISE annual Conference), IIT Guwahati, 3rd – 5th December, 655 – 659. [ISBN 978-93-392-1970-3]

3. **Sanjog J.,** Patel, T., Chowdhury, A., Kumar, S., and Karmakar, S. (2013). Ergonomics investigations across durable goods manufacturing sector in India: an insight, In: Proceedings of International Conference on Ergonomics and Human Factors, "Ergo 2013: Ergonomics for Rural Development" HWWE-2013, (11th ISE annual Conference), Vidyasagar University, West Bengal, 4-6 December, 183-189.
4. **Sanjog, J.,** Chowdhury, A., and Karmakar, S. (2012). Industry Specific Applications of DHM. In: Karim Abdel-Malek edited 'Proceedings of the International Summit on Human Simulation (ISHS-2012)', 23-25 May, 2012, St. Pete Beach, Florida, USA, 123-134.
5. **Sanjog, J.,** Chowdhury, A., and Karmakar, S. (2012). Digital Human Modeling Software in Secondary Manufacturing Sector: A review. In: Proceedings of International Conference on Recent Trends in Computer Science and Engineering (ICRTCSE-2012), 3-4 May, 2012, Chennai, Tamil Nadu, India. AEC12397. [ISBN 978-81-9089-807-2]

Papers under review

1. **Sanjog, J.,** Patel, T., Karmakar, S. Scenario of Occupational Environment in Injection-molded Plastic Furniture Manufacturing Factories of North East India. Indian Journal of Science and Technology.
2. **Sanjog, J.,** Patel, T., Karmakar, S. Implementation of simple ergonomic design interventions to overcome physical risk factors in injection-molding workstation of plastic furniture manufacturing industry. International Journal of Industrial Engineering: Theory, Applications and Practice.