CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Researchers all over the World are studying about the factors causing discomfort to industry workers during their regular work. This chapter provides insight into information available in literature related to the usage of industrial trolleys and associated works. Solutions for various problems related to pushing and pulling trolleys are brought out from literature and the need for further research in this area is highlighted.

2.2 LITERATURE REVIEW

2.2.1 General review

Corlett and Bishop (1976) proposed a technique for finding discomfort in body. Figure 2.1 shows the body regions. Continuous monitoring of discomfort helps in identifying problems in the design of workstation. When comparing the results with productivity, benefits of principles of ergonomics can be documented. Case study of spot welders was done as an illustration. Two methods were used to identify workplace problems. First method was by observing the workforce and the second method was by observing the work task for identifying ULDs. HSE
(2002) reported that, upper limb disorders (ULDs) are to be identified by every member of the group. Feedbacks from workers are to be obtained using the principles of ergonomics. The maximum capacity of workers was to be considered while designing work to promote health, safety and productivity. ULD problems are effectively dealt by applying the principles of ergonomics, since it considers all details of design of work and feedback from workers. ULD analysis uses the following:

![Body Regions Diagram](image)

**Fig. 2.1 Body Regions (Corlett and Bishop, 1976)**

- Sick leave records
- Jobs neglected by workers
- Jobs which are difficult to perform
- Workers conforming to workstations
- Workers who try to change jobs
- Medical treatment received and Medication to avoid pain
Biman Das et al. (2002) redesigned hospital trolley using the principles of ergonomics. The users had difficulty in giving initial push to the trolley, in turning the trolley and to stop the trolley. The users experienced discomfort in different parts of the body. The push forces exceeded the lower permissible limit. Suggestions were made for changing the location of handles, handle diameter, large wheels with tyres, lesser trolley height, use of plastic material, and reduction of the meal tray size.

Irad Ben-Gal and Joseph Buckhin (2002) reported that A new structural methodology for workstation design. Factorial experiments and RSM are integrated for reducing the number of solutions for obtaining the best design for multi objective requirements.

Jung et al. (2005) indicated the relationship between manual vehicles, operating conditions and human factors. He has emphasized the need for classifying manual vehicles for focusing on ergonomic design. Such classification will be useful to designers for concentrating on further improvement of designs. The working conditions available in industries may increase discomfort to workers if floors and equipment are not maintained properly.

Christin et al. (2010) developed equations for setting up limits for manual materials handling activities for protecting the spinal column. Psychophysical data, biomechanical analysis and physiological criteria were used in sequence. Both task and personal factors were considered in the models' development. The developed load capacity limits are lower than previously established limits.
Castro et al. (2012) studied the maximum thrust exerted in different positions of shoulder and elbow. Eight males and eight females took part in the push-pull experiment in sixteen positions using both arms in sequence by pushing or pulling a dynamometer for a period of three seconds as hard as possible. The results were presented in tables along with the mean, standard deviation and range of force levels in different positions.

Jaswinder Singh et al. (2014) reported that multi response optimization of process parameters like Taguchi based optimization use the available practical knowledge. But, there are some confusions and uncertainties. A combination of utility theory and Taguchi quality loss function was found to give better results.

2.2.2 Musculoskeletal problems

Alwin et al. (2003) published a document on the prevention of musculoskeletal disorders through World Health Organization (WHO). Guidelines are given to employers for avoiding or minimizing the risks of physical loading and unnecessary fatiguing. This document helps supervisors to design work and work environment. Occupational health trainers can gather material for occupational health training. Applications of this guide reduce harm to individuals and influence the work positively.

European Agency (2006) reported that MSDs are caused by manual handling. In Europe, increase in low back disorders was significant. Back pain tops the list of MSDs. Most of the workers working in agriculture, transport, construction and communication sectors are found to
have MSDs. WMSDs may affect the ability of affected workers to work and to enjoy leisure activities during the rest of their lives. Therefore, prevention of MSDs was important.

**Alireza et al. (2007)** conducted a study with the objectives of a) determination of WMSDs prevalence and b) assessment of exposure level to WMSDs risks. Eighty five workers took part in this study. Nordic musculoskeletal questionnaire (NMQ) and rapid upper limb assessment (RULA) technique were used for the study. Seventy three percent of the respondents have discomfort in shoulders, sixty seven percent in knees and sixty seven percent in back. RULA showed that eighty eight percent of the cases have action levels three and four. It was found that redesigning of workstations would reduce WMSDs.

**Ulrich Glitschetal. (2007)** presented results of laboratory experiment as well as visual analysis in aircrafts. Musculoskeletal loads due to pushing and pulling were analyzed. 15 flight attendants took part in the study in 10 short-route flights. 3D measurements of forces and postures were recorded. Around 200 trolley movements take place in a shift. More loads were experienced when the trolleys were full and during takeoff when the floor in inclined upwards. Musculoskeletal load depends on the quantity of food available in the trolley and on the inclination of the floor. The discomfort experienced is based on the human factors, type of trolley and inclination of the floor. Vertical forces sometimes exceeded horizontal forces required for pushing/pulling. Awkward postures were occupied especially during pulling. Half-size trolley caused more discomfort. Female flight attendants are more prone to experience more discomfort while fully laden trolleys unaided in inclined floor.
Schaub et al. (2007) reported that, food services are provided in short duration flights also. Flight attendants are experiencing MSDs while handling trolleys. Forces exerted by flight attendants are compared with maximum limits as per international standards. It was found that they exert more than allowable forces especially when the floor in inclined. Handling of half size trolley was found to be difficult due to higher location of centre of gravity.

OSHA (2012) provides solutions for MSDs experienced by industrial workers. It reports that workers working in foundry units have more MSDs compared to general industries. But, many solutions are given using ergonomic principles to make the work less stressful.

Worksafe (2013) reports that workers are required to bend their backs while placing products in the trolley below the waist level repeatedly. Musculoskeletal injuries occur gradually over time through wear and tear of joints and other body components. If the products are kept at waist height as shown in Figure 2.2, injuries can be reduced. This allows employees to undertake this part of the re-stocking task in an upright posture. The trolley should have:

- a height-adjustable base
- leg space so that workers are able to walk without hitting the trolley
- products in waist height so that worker can see clearly the path in front of the trolley
- low-resistance bearings and large castors
- routine maintenance
**Fig. 2.2.** Products are to be placed at waist height (Worksafe, 2013)

Somnath and Samrat (2014) reported that improper workstation, work procedures and tools develop musculoskeletal disorders among workers. Such adverse conditions can be improved by ergonomic interventions. They have reported studies related to design interventions and analysed their effects in agricultural and informal sectors. Awkward postures were corrected and productivity increased.

### 2.2.3 Handle height

Worksafe (2004) reported that the preferred height for pushing or pulling is different for different workers. Height adjustable handles are provided only in a few carts. Handle height has to be between elbow and hip for pushing and between hip and knee for pulling. If the load is stable on the trolley, the worker can push the load to move the trolley. Handle heights in the range of 760 mm to 1200 mm is suggested for pushing and from 660 mm to 1000 mm for pulling.
**John Culvenor (2005)** reported that trolleys are used for solving the problems associated with lifting and carrying. Experiments were conducted to move trolleys loaded with 160 kg and 400 kg. It was found that the preferred handle height was in the range of 1200-1350 mm. The relationship between the handle height and the push force was found to be linear.

**Andrew (2005)** gathered data from workers which are useful in the design of MMH trolley (handle height, handle angle, wheels, load, force and posture) workstations, tools, equipment, layout designs and interventions that are uniquely well-suited for workers. In addition, this information is used in the improvement of local working conditions, targeting key problem areas in order to minimize ergonomic problems and related injuries and illnesses.

**Hwa- S. Jung et al. (2009)** reported that safety during handling boxes depends on the handles and their positions. Optimal position of the handles was found using the evaluated user preferences and body part discomfort (BPD). Twenty male students volunteered and took part in the experiment. Handles on the upper part preferred for smaller boxes and middle part preferred for medium and heavy boxes. Correct position of the handles increase user satisfaction.

**Ray Cislo (2014)** discussed the range of handle height. Efficient pushing or pulling takes place at a preferred height. Many trolleys are not fitted with adjustable handles. For pushing the handle should be between elbow and hip and for pulling, it should be between hip and knee. To accommodate workers various heights, handle heights between 760 to 1200
mm suggested for pushing and 660 mm to 1000 mm recommended for pulling. Figure 2.3 shows the handle height and posture.

![Fig. 2.3 Handle height and posture (Ray Cislo, 2014)](image)

**Lowndes et al. (2015)** reported that injury may occur due to vibrations, awkward postures and repetitions. Health may be affected when lawn mowers are used due to these reasons. Natural posture of work may reduce upper limb injury. Four different positions as shown in Figure 2.4 and three different grip spans were tested. The recommendations are: a tilt between forty-five and seventy degrees, forty eight to seventy eight degrees of handle rotations and lesser force and smaller grip span.

**Rosie and Ira (2015)** found that trolley handle design affects body posture, hand grip and force application. For 70-80% of users, shoulder height is the recommended handle height. Handles falling in this range reduce the strain on the wrists and hands and reduce compression load at L5-S1 (lower back). Horizontal handles offer high stress due to bent wrist. Vertical handles accommodate natural wrist posture and users can grip the handle according to their convenient height.
Fig. 2.4 The handle mock up in each position (X) position, the comfort position (C), Vertical position (V) and Pistol Position (P) (Bethany R. Lowndes et al., 2015)

Pradip Kumar and Jhareswar (2018) reported that worker should be able to handle trolleys easily and to store products easily. Trolley should be light in weight. Handle height should be such that it reduces the mechanical effort applied by the user and it reduces the strain. For minimising the effort, the handle height should be kept between the hip and elbow height.
2.2.4 Pushing and Pulling

Darcor and Ergoweb (2001) reported that there is no single recommended handle height for pushing. A range of handle height from 740 mm to 1200 mm may accommodate 90% or the American working population. For Pulling, a range of handle height from 460 mm to 990 mm may accommodate about 90% of the American working population.

Jorrit et al. (2002) compared a catering cart with prototypes having castor wheels and push bar. They found that more forces were required to push prototypes with reversed starting position using bigger castors. Higher forces were required to stop the prototypes using bigger castors due to lower rolling friction. Prototypes were more favourable during the sustained phase. Porotypes with vertical bars reduced the time-integrated pushing forces. It was found that it is advantageous to provide an axis of rotation using fixed wheel.

Biman Das and Yanqing Wang (2004) experimentally calculated the push and pull forces exerted by male and female subjects in sitting as well as in standing positions. They found that 400 N is the maximum pull exerted by male subjects. Females exerted 222 N while sitting and 244 N while standing. Males could exert a push force of 227 N in sitting position and 251 N in standing position. Females could exert 96 N in sitting position and 140 N in standing position.

Agrawal et al. (2009) conducted a study and collected data on male and female agricultural workers of Meghalaya, India. Data were collected from 52 male subjects and 48 female subjects. The 5th and
95\textsuperscript{th} percentile values of different strength parameters were estimated, which are to be considered while designing the various machinery controls. The strength values presented in this paper are useful for setting limits for designing manually operated equipment involving push/pull activities, leg strength, torque limits.

**Arun Garg et al. (2014)** agree with the recommendations of Snook and Cirello for pushing and pulling forces. They have provided regression equations in terms of handle height, distance of travel, frequency, push and pull forces. They have also recorded that it is difficult to find the optimal handle height. The discussions given in this work are useful for industrial design.

**Ray Cislo (2014)** presented the following guidelines: Push the load instead of pulling it as shown in Figure 2.5.

- The trolley may cause injury to legs when pulling it.
- If both hands are stretched behind body shoulder and back will have injury.
- If the trolley is pulled by walking backwards, the person cannot see the path.
- Pushing force will be augmented by the body weight.

![Fig. 2.5 Pulling or pushing](image)

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Amy et al. (2016) presented guidelines for Pushing and pulling task by considering shoulder physical capacity based on gender, handle height, exertion type (push or pull) and handle orientation for these tasks. Pushing and pulling comprise nearly half of all manual materials handling tasks. Ergonomists assess, design or modify these tasks while incorporating constraints, including manual force direction and handle interface.

Andreas et al. (2017) studied the cart weight, handle position, exerted forces, push/pull and task experience. The most influential factors were found to be the cart weight and external load. Ideal handle positions ranged from hip to shoulder height. Strain reduced based on task experience and handling techniques. Work places involving pushing and pulling should be checked for best practices in handling to reduce musculoskeletal problems.

2.2.5 Muscle activity measurements through sEMG

Jer Hao Chang et al. (2005) reported that joint kinematics can be investigated conveniently using a flexible electro-goniometry. During their daily work, patients can wear the flexible goniometer without any difficulty. An investigation protocol for wrist evaluation may evolve based on this work which may improve biomechanical interpretation and treatment. Figure 2.6 shows the experimental system followed by Jer Hao Chang et al.
Theado et al. (2007) developed person-specific biologically assisted models and understood the spine loading under push pull conditions. They modified EMG-assisted biomechanical model designed for evaluating lifting tasks to evaluate push pull tasks. Results indicated that the modification was successful. The modified model would be useful to industries for evaluating push and pull tasks.

Srinivas and Venkatesh (2007) studied the muscle fatigue using sEMG in cyclists with and without low back pain (LBP). They have found that conditions of persons having LBP may worsen due to cycling.

Chih-Long Lin et al. (2009) evaluated the force exertions and muscle activities in MGV operations. They found that the force direction, handle height and load handling effects are significant. The pushing and pulling force at 1150 mm handle height was found to be less compared to 1015 mm and 880 mm handle heights. 150 mm wheels required less force compared to 200 mm wheels.
Jennifer and Peter (2010) showed that the performance of multiple tasks increase muscle activity. Flexor activity decreases with grip only; forearm extensor muscle activity increases during all push with grip tasks. By using strategies, forearm muscle loading can be decreased in the workplace.

Isa Halim et al. (2012) analyzed muscle activity using sEMG (surface electromyography) continuously for 5 hours. A survey was carried out using a questionnaire apart from sEMG measurement. Prolonged standing was found to contribute psychological fatigue and muscle fatigue. Figure 2.7 shows the attachment of surface electrodes over muscles.

![Fig.2.7 Surface electrodes attached over erector spinae muscles, gastrocnemius muscles and tibialis anterior muscles](image)

Fig.2.7 Surface electrodes attached over erector spinae muscles, gastrocnemius muscles and tibialis anterior muscles (Isa Halim et al., 2012)

Fewster et al. (2015) reported that determination of manual arm strength limits is difficult when the force vector passes directly through the elbow and shoulder. Sixteen participants took part in the experiment in which they were asked to generate isometric in-line arm forces at varying intensities. To monitor individual muscle activity, surface electromyography was used to make inference about elbow stability. 25th percentile maximum in-line arm push force was found to be 636 N for males and 359 N for females.
**Wu et al. (2017)** reported that grip force estimation and push-pull force from EMG are important. An action force estimation method based on the 8 channels of sEMG is presented. A grip force sensor and a force sensor are used to measure the output force of the human’s hand. They found that sEMG correctly estimates the output force of the human hand. Figure 2.8 shows the EMG signals and the corresponding grip force.

![Figure 2.8 The EMG signals and the corresponding grip force](Changcheng, 2017)

### 2.2.6 Heart rate measurements

**Jones et al. (2003)** investigated the effect of posture on the heart rate (HR). ECG was taken in lying, sitting and standing positions. Standing HR was higher than that in sitting or lying positions. It was found that body posture has an effect on HR and the changes are due to orthostatic haemodynamic stress as well as changes in cardiac electrical axis.
Keytel et al. (2005) quantified the effects of training, body composition and exercise on the relationship between physical activity energy expenditure and heart rate. Regularly exercising individuals underwent a test for maximal oxygen uptake (VO₂ max test). The participants carried out three steady-state exercise stages on the treadmill (10 min) or the cycle ergometer (15 min) at 35%, 62% and 80% of VO₂ max, corresponding to 57%, 77% and 90% of maximal heart rate. Based on these results, it was concluded that it is possible to estimate physical activity energy expenditure based on heart rate.

Juhani et al. (2007) reported that usually, individual HR/VO₂ calibration curves are required for estimating oxygen consumption (VO₂) at work using heart rate (HR). They developed a new neural network, and heart rate variability-based method without individual calibration (VO₂-HRV) for the estimation of VO₂. They found that the VO₂-HRV is a potentially useful method without laboratory calibration for estimating VO₂.

Kamalakannan and Groves (2007) developed predictive equations to estimate metabolic work rate (MWR) as a function of heart rate and physical characteristics. Thirteen subjects (5-Female, 8-Male) in the age group of 22-55 years performed a series of tests on oxygen consumption and heart rate. Predictors considered for modeling were: heart rate (HR), resting heart rate (RHR), age (A), gender (G), height (HT), weight (W), body mass index (BMI), predicted work rate (PWR) and slope (S). The developed four models and linear regression were used to evaluate them. The best model is given below. It was found that the model can be used for prediction of MWR without collecting metabolic work data.
MWR = - 145 + 0.0249*RHR*PWR + 67.7*A*G*S - 0.172*G*RHR -
0.560*PWR + 0.230*A*G*B - 0.101*A² + 0.0978*H*HT - 0288*W*S*PWR

Danielle and Francois (2008) evaluated the reliability of the oxygen consumption/heart rate (VO₂/HR) relationship used to estimate energy expenditure during a workday. They found that good reliability exists between VO₂/HR relationship and HR usually found in workplaces.

Przybyszewski (2011) predicted energy expenditure from physical heart rate, activity and anthropometry of female tea pluckers of India. An accelerometer, Polar heart rate monitor and a K₄b₂ indirect calorimeter were used in the study. The period of experiment was 90-minutes for assessing physical activity, heart rate and energy expenditure. The study concluded that energy expenditure can be accurately predicted based on heart rate, physical activity, weight, age, and height for any population.

First Beat (2012) Energy Expenditure (EE) method has high accuracy, easy to use and is inexpensive. Error is in the range of 7-10%. This method allows measurements during dynamically changing and resting conditions. As a non-invasive measurement, it can be applied to both professional and personal purposes. This method can be used for calculating energy expenditure using heart rate measurements in research laboratories and fields.

CDC (2015) reported that a person's target heart rate should be 50 to 70% of his or her maximum heart rate for moderate-intensity physical
activity. This maximum rate is based on the person's age. By subtracting the person's age from 220, an estimate of a person's maximum age-related heart rate can be calculated. For example, for a 50-year-old person, the estimated maximum age-related heart rate is calculated as 220 - 50 years = 170 beats per minute (bpm). The 50% and 70% levels would be:

- 50% level: 170 x 0.50 = 85 bpm, and
- 70% level: 170 x 0.70 = 119 bpm

Thus, moderate-intensity physical activity for a 50-year-old person will be between 85 and 119 bpm during physical activity.

2.2.7 Wrist movement

Hansson et al. (1996) reported that in occupational MSDs, quantitative measurements of workload are required. The movements of wrist are of interest in upper limb disorders. A biaxial electro-goniometer was used for measuring the flexion, extension, abduction and adduction of wrist. These measurements give the amount of risk involved in different movements of the wrist.

Kristensen et al. (2001) studied postures and movements during repetitive work using video-based observations and inclinometers and goniometers. The mean power frequency (MPF) of the electrogoniometer data and the number of repetitive movements/minute were related, showing both variables are measures of repetitiveness. They concluded that, the technical measurements and the observation method supplemented each other well.
Peregrin et al. (2001) reported that prevention of WRMSD is a national priority in many countries. Research works are carried out for quantifying these exposures to set upper limit values. In this work, a comparison between the following three methods is reported: (i) questionnaires, (ii) video analysis and (iii) measurements using goniometer. It was found that the precision of the results through questionnaires were low resulting in over estimation. Electrogoniometer was used for measuring wrist flexion/extension duration and repetition. Electrogoniometric measures of wrist deviation duration and frequency were found to be less precise than video analysis. Electrogoniometer and electromyography (EMG) measurements of grip force and velocity, forearm rotation duration and repetition, were found to be the best.

Balogh et al. (2009) reported that, in most hand-intensive work, Goniometry of the wrist is a feasible method for studying wrist movements. Accuracy and precision of the method are good. Six subjects carried out three different hand-intensive work tasks: picking materials, light assembly and heavy assembly. The measured positions were found to be precise and good, the precision of goniometry was on par with inclinometry.

Gustafsson et al. (2009) reported that electro goniometer can be used for measuring the positions of wrist or thumb positions. Manual goniometry is considered to be a valid method when measuring postures in computer users. Electrogoniometer can be used for measuring postures and movements in ° or °/s. Electro goniometry measure gives data about the mean power frequency (MPF).
Scott Rud (2011) reported that MSDs are developed due to pulling and pushing. They used RULA, REBA and the NIOSH lifting equation for creating a baseline for comparison. To make sure that the compilation of assessment method are right, ergonomic instruments such as the manual goniometer, digital inclinometer, video analysis, and the hydraulic push pull dynamometer were used.

Fabiana et al. (2013) reported that human movement recording is important for assessing variations in postures, analyzing occupation and for preventive programs in rehabilitation. Electro-goniometer is an accurate device used for recording the movement of skeletal joints. Corrections procedures are not required while performing the experiments.

IFA (2013) presented CULEA (German acronym for "computer-based measurement and long-term analysis of musculoskeletal workloads") measuring system and their attachment to test subjects. The basic system consists of goniometers and inertial sensors. The system is worn under the working clothes. It records movements of the back and lower extremities and can be extended to record 3D movements of the upper extremities and head. Pressure measuring soles can be used to measure floor reaction forces simultaneously by foot. It is possible to calculate the handled load weights from the floor reaction forces with the aid of a biomechanical human model even during dynamic movements.

2.2.8 Spinal load due to pushing

Lee et al. (1991) estimated lower back loadings in cart pushing and pulling. Laboratory experiments were conducted using a trolley. Six
subjects with different weights (ranging from 50 to 80 kg) were tested for three different pushing and pulling forces (98, 196 and 294 Newtons), three different heights of exertion (660, 1090 and 1520 mm high) and two different moving speeds (1.8 and 3.6 km/h). Pushing a cart resulted in lesser lower-back loading than pulling. Subject body weight affected the lower-back loadings more significantly in pulling than in pushing. A handle height of 1090 mm was found to be better than other handle heights in pushing while 1520 mm handle height was better for pulling thereby reducing lower-back loadings.

The variables considered for the biomechanical model are: subject's body weight, subject's stature, hand force, handle height and various interactions of these variables. The stature/handle-height relationship was bio-mechanically more important to the compressive forces than the subject's stature alone. This ratio represents the relative height of the handle compared with the stature. Therefore a new variable, height factor, which represents this ratio was defined and used instead of stature and handle height as follows:

Height factor, \( H = \frac{\text{stature} - \text{handle height}}{\text{stature}} \)

The following relationship between the peak compressive force at the L5/S1 disc and the independent variables as given by Lee et al.

\[
Y_{\text{pushing}} = 298 + 16.62W - 2261.86H + 0.0254WF + 12.67FH
\]

Where  \( Y_{\text{pushing}} = \) peak compressive force at L5/S1 disc in pushing  \( W = \) subject weight (kg),  \( H = \) height factor  \( F = \) horizontal hand force (N)
Marc L. Resnick et al. (1995) observed that a lot of changes in design of handling equipment happened due to awareness of principles of ergonomics. Material handling equipment requires pushing or pulling. A study was carried out as shown in Figure 2.10 to study the performance of workers and the resulting stresses. Four persons having different strengths pushed carts loaded with 45 to 450 kg. Male subjects could push upto 500 Newtons and female subjects 200 Newtons. When the load was 225 kg, the load on the spinal column exceeded the safety limit set by NIOSH, i.e. three thousand four hundred Newtons.
Ayoub and Jeffrey (1999) reported that Ergonomics practitioners are often confused by conflicting recommendations provided by different models available in literature. They recommended that models are to be related to the musculoskeletal risks of jobs and careers, instead of tasks. The greatest requirement to prevent MMH injuries was to understand the cumulative effects through the career as a whole.

Bjarne and Bente (2002) conducted push pull experiments using a two wheeled container as shown in Figure 2.11 on 3 different surfaces. Shear forces in the lumbar spine at the L4/L5 level was calculated. The lumbar spine compression force was below 1800 N and the shear force was below 200 N. The push/pull forces were affected by the load and surface type but the load on the spinal column was not affected by the load or the type of surface.
Fig. 2.11 A person (waste collector) pushing and pulling a waste container on flagstones (Bjarne et al., 2002)

Jim R Potvin (2008) reviewed the literature and gave an introduction to spine biomechanics for understanding low back injuring and their prevention at workplace. The review areas include manual material handling and ergonomic assessment tools. Future research directions in biomechanics are suggested.

Gregory and William (2009) reported that MMH tasks are being converted to pushing and pulling from lifting. The load on the spine due to pulling was more compared to that of pushing. One fifth of the body weight appeared to be the maximum force which any person can exert during pushing or pulling. These findings help us to understand the nature of spine loads and low back risk during modern times. Figure 2.12 shows the experimental set up used by Gregory and William (2009).
Fig. 2.12 Experimental set-up used by Gregory and William (2009)

Karla Gomes-Bull (2012) identified the level of risk in the MMH task and provided guidelines for reducing it, to prevent the presence of MSDs, and to increase the production. 3DSSPP® software and Ovako Working Analysis System (OWAS) technique were used for the evaluation. To perform task analysis, a 15-minute video was recorded during normal operation condition. To obtain estimate metabolic rate, heart rate was monitored and recorded. This task was found to have high metabolic rate, which affects the performance of the worker. An unacceptable compression force level at L4-L5 intervertebral disc was observed. Cart redesign incorporating ergonomic principles, was suggested for reducing forceful exertions while pushing the cart for preventing the musculoskeletal injuries and disorders.
Ashish et al. (2013) quantified the effect of dynamic cart pushing exertions on the biomechanical loading of shoulder and low back. 10 participants took part in cart pushing tasks on flat (0°), 5°, and 10° ramped walkways at 20 kg, 30 kg, and 40 kg weight conditions. An optoelectronic motion capturing system using two force plates was utilized for the kinematic and ground reaction force data collection. The experimental data was modeled using Any Body modeling system to compute three-dimensional peak reaction forces at the shoulder complex and spinal joints as shown in Figure 2.13. The main effect of walkway gradient and cart weight, and gradient by weight interaction on the biomechanical loading of shoulder complex and low back joints were significant. It was found that shear loading of the spinal joint, may contribute to the risk of work-related low back and shoulder musculoskeletal disorder with prolonged and repetitive use of carts.

Fig. 2.13 A cart pushing model developed using Any Body modeling system (Ashish et al., 2013)
2.2.9 Need for more research

Andrew (2005) reported that there was evidently a need for future research to clarify the findings regarding optimal handle height for both pushing and pulling tasks in order to minimize the risk of placing excessive strain on the musculoskeletal system, while at the same time minimizing the likelihood of slip, trip and fall accidents.

Terry Bossomaier et al. (2010), reported that, over the last years ergonomic problems have received growing attention due to their effects on industrial plants efficiency and productivity. Many theories, principles, methods and data relevant to the workstation design have been generated through ergonomics research. However, no general frameworks have been suggested, yet. Two main scientific approaches have been identified. The first approach was based on the direct analysis of the real workstations, while the second one uses computerized models to design workstations ergonomically.

2.3 CONCLUSIONS FROM THE LITERATURE REVIEW

According to the literature review and the survey of the industrial trolleys it was found that there was a gap in the technology in designing the MMH trolley. The principles of ergonomics are yet to be incorporated while designing a trolley. The trolley should be designed to match a set of population who are working in the industry. The wheel size has to be matched according to the load and the floor conditions.

Based on the research findings of Ray Cislo (2014), Chih-Long Lin et al. (2009), and Darcor & Ergoweb (2001) five handle heights ranging
from 900 to 1100 mm with an equal interval of 50 mm has been selected. Three wheel sizes 100 mm, 125 mm and 150 mm diameter were selected for the trials. Five different loads 125, 156, 188, 219 and 250 kg were selected to load the trolley for conducting experimental trials.

Based upon the anthropometric data of the industrial workers, the trolley (handle height) they used, and the variation of loads within the range 100 to 250 kg and data from the literature provided by Ray Cislo (2014), Chih-Long Lin et al. (2009), and Darcor & Ergoweb (2001) ranges for the wheel sizes, Handle heights and the loads were chosen.

2.3.1 Thesis Overview

The thesis is organized as follows:

Chapter 1 provides the background of the research work, motivation for taking up this research.

Chapter 2 provides the literature review on the various manual material handling equipments used in the industries. The definition, classification and limitations of the MMH trolleys are highlighted. Recent developments in the industrial trolleys and its limitations are reported. This chapter also gives the information on the conclusions drawn from the literature review, problem statement, objectives and methodology.

In Chapter 3, description of the methods and materials, experimental procedures are listed. Description and specifications about ergonomics assessment tools like Ergokit, force gauge, data acquisition kit,
surface electromyography (sEMG), goniometry and Polar heart rate (HR) sensors are provided. Details about design of experiments (DoE), response surface methodology (RSM) and experimental design using central composite design (CCD) are provided. Description and merits of newly developed industrial trolley is included.

In Chapter 4, Results and discussions on the following topics are presented: effect of handle height, effect of wheel diameter, initial, sustained and ending push analysis, heart rate analysis, surface electromyography analysis in terms of percentage of muscular voluntary contractions (%MVC) and muscle activity of all the five subjects involved in the experimental work. Results of bio-mechanical analysis and optimization are presented. A theoretical biomechanical model and experimental results are presented. The results of optimization using genetic algorithm is also presented.

In Chapter 5, conclusions and scope for the future work are presented.

2.4 OBJECTIVES AND METHODOLOGY

2.4.1 Objectives

1. To make a survey of the problems faced by the industry workers and to study the material handling systems at a gear manufacturing industry.

2. To experimentally analyse the designed and fabricated industrial trolley as per ergonomic principles and to find the comfortable handle height and wheel diameter for the industrial trolley by using push-pull analysis, surface Electromyography analysis, heart rate analysis and Goniometer analysis.
3. To conduct a bio-mechanical analysis and an optimization technique to validate the results obtained through experiments.

2.4.2 Methodology

A flow chart of the research plan is given in figure 2.14. The following are the steps involved in the research plan.

- Literature Review
- Study of manual material handling devices in the industry
- Design and fabrication of a new MMH trolley
- Experimental Investigations on Handle height, and wheel diameter of industrial trolley. Force analysis using push pull gauge sEMG, Goniometer and heart rate analysis
- Bio-mechanical analysis and Optimization
- Publications and Documentation

Fig. 2.14 Flow chart of the research plan
2.5 PROBLEM STATEMENT

The available push pull trolleys are studied and the problems faced by workers while using trolleys for manual material handling in the industries are identified. The workers working in the industry reported WRMSDs when approached and taken a survey. Inspite of the use of trolleys in the industry, a lot of lifting and carrying activities are observed among the workers.

An attempt has been made to ergonomically design and fabricate a trolley with adjustable handle height to suit the worker’s comfort. This trolley is fabricated and tested on five different subjects using five different handle heights and three different wheel diameters and the results are presented.