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Ergonomic Evaluation of Billet Mould Maintenance Using Hierarchical Task Analysis, Biomechanical Modeling and Digital Human Modeling

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ABSTRACT

Work related musculoskeletal disorders (MSD) are common in maintenance tasks arising out of man-machine incompatibility. A hybrid methodology integrating hierarchical task analysis (HTA), posture analysis (REBA), biomechanical modeling, and digital human modeling (DHM) is sequentially applied to a mould maintenance job. Among the 29 tasks identified using HTA, 5 tasks namely 'striking with mallet', 'positioning oiler plate', 'fastening oiler plate', 'positioning top plate', 'fastening top plate' are under 'high severity' category based on REBA scores. From biomechanical modeling, it is observed that all the five L5/S1 peak loading values corresponding to dynamic analysis (4069 – 5701 N) and most of the peak loading values corresponding to static analysis (2948 – 5707 N) exceed the threshold (e.g. NIOSH 3400 N). The workstation for the maintenance job is redesigned using DHM. The new design has reduced the compressive force at L5/S1 from 2948 - 5707 N to 2010 - 2637 N.

Keywords: hierarchical task analysis, biomechanics, digital human modeling, steel industry.

1. INTRODUCTION

Maintenance job is the integral part of all industrial activities involving machines and infrastructure, and both mentally and physically demanding. The variable physical exertions, variable postures, variety of material and tools used and variable task contents within a restricted space may pose enormous physical load on the workers. But literature on workload assessment and intervention methodology for maintenance tasks are scarce. Lind et al. [24] highlighted on the need of safety risk assessment tool for maintenance tasks catering to multiple work specifications or requirements including those of ergonomic demands. Posture analysis of maintenance tasks was done by several researchers [1],[6], [8],[21],[29]. Karhu et al. [21] illustrated the application of Ovako working posture analysis system (OWAS) in the installation and maintenance of steel mill equipment. Joode et al. [6] conducted a workplace survey on ship maintenance and mentioned the distribution of awkward work postures over worktime. Moriguchi et al. [29] studied postures and movements of power line workers using inclinometers. To undertake interventions to alleviate the ergonomic issues a careful examination and assessment of exposures to various risk factors is essential. Task analysis, observational analysis, biomechanical analysis and digital human modeling are some of the methods being employed to evaluate a work system.

This paper attempts to present a hybrid methodology describing and quantifying an intervention pathway from 'subjective information' and 'subjective evaluation' to 'quantitative evaluation' and 'redesign' along with a case. The overall goal is to propose an effective approach for workplace evaluation to identify man-machine mismatches and redesign in the digital environment using billet mould maintenance job performed in a steel industry as an example.

After the introduction, the paper in the second section presents the literature review to cover the overall theoretical background for this study covering task analysis, postural analysis, biomechanical analysis, digital human modeling and intervention framework for maintenance. In the third section the methodology is described, and in the fourth section results of a case study in an integrated steel plant are presented. In the fifth section, limitations of the study are presented and finally, the conclusions are reported.

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2. LITERATURE

Task analysis of maintenance activities has revealed it a complex sociotechnical system requiring above average coordination, communication, and cooperation between inspectors, maintenance personnel, supervisors, and various other sub-systems such as planning, stores, clean-up crews, and shops to be effective and efficient [17]. The literature is primarily focused on decision making and related human errors [7]. Hierarchical Task Analysis (HTA) is widely used due to its inherent flexibility to describe any system and its ability to be used for many applications [36].

A number of posture analysis methods are available today such as Ovako Working Posture Analyzing System (OWAS), Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), Hands relative to the body (HARBO), Posture-Activity-Tools-Handling (PATH), and Chung's postural workload evaluation [38]. Such observational tools are simple, cheap and less time consuming but cumbersome and subjective in judgments. This makes the measurements suffering from low precision, and questionable internal and external validity [20]. Biomechanical modeling and analysis overcomes such subjectivity. The challenge is in capturing and processing human motion from field environment for further biomechanical analysis. Recent advances in motion capturing, direct measurement tools and associated methodologies have helped in overcoming some of the limitations of observational ergonomic tools and evaluations [9,10], [24,25]. These developments have strengthened intervention design focus and efforts [14], [31].

Digital human modeling (DHM) has been used for proactive ergonomic workplace evaluation and its design/redesign [2],[5],[12,13],[19,20], [24,25]. Virtual technology allows ergonomists and engineers to perform virtual builds, and the tools are applied in the design, modification, visualization and analysis of human workplace layouts and/or product interactions [26]. For improvement of the physical aspects of a work system, DHM tools allow a designer or engineer to create an avatar (virtual human) with specific population attributes on their personal computers, which can then be inserted into their 3D graphic renderings of their proposed designs. Some of DHM software include Jack, Safework, AnyBody and UM-3D Static Strength Prediction Program. The benefit of DHM includes lower design time, improved design options and lower cost. Though DHM has been used extensively for ergonomic and safety analysis, there is emphasis now to evaluate maintenance and assembly tasks [8],[10],[16],[28],[32],[35], [40], [43].

From an ergonomic evaluation perspective of maintenance tasks, the literature is providing diversity in the methodology adopted. For example, Joode et al. [6] used an observational method, Kazmierczak et al. [23] used multiple methods for evaluation, Udo et al. [35] used qualitative/participative method, Moriguchi et al. [30] used direct measurement method, Maatta [29] used 'Safety Analysis and Virtual Environments' (SAVE) framework, Reed et al. [34] used Human motion simulation (HUMOSIM) ergonomics framework and Chaffin [3] used a generic framework of task analysis, Yuviler-Gavish et al. [43] used HTA based methodology for ergonomic evaluation of industrial maintenance and assembly in developing VR simulators for training purpose, Di Gironimo et al. [10] used MTM based study incorporating ergonomic factors to estimate maintenance times for automotive maintenance tasks, Qiu et al. [32] developed a virtual human hybrid control method for improved virtual assembly and maintenance simulation.

3. METHODOLOGY

The methodology comprises four modules in sequence. They are, HTA, posture analysis, biomechanical modeling and DHM as given in Fig. 1. The following section briefly describes these modules.

3.1. Hierarchical Task Analysis

Module I involves hierarchical Task Analysis (HTA) to model maintenance tasks by defining goal and the required activities to achieve the goal. HTA comprises three main principles [36], (i) system level operation defining the objective of the system (goal), (ii) sub-goals or sub-operations, and (iii) relationships between operations and sub-operations (hierarchical relationships). The hierarchical number scheme for HTA required that every sub-goal was uniquely numbered with an integer in sequence. Each sub-goal was further identified by stating its super-ordinate goal and its position under that sub-goal (see for example, Fig 3(a)). HTA is used to capture the qualitative information in the task elements. HTA comprises three main principles [36] as (i) system level operation defining the objective of the system (goal), (ii) sub-goals or sub-operations, and (iii) relationships between operations and sub-operations (hierarchical relationships).

3.2. Posture Analysis

Module II involves observational posture analysis using REBA. REBA is chosen because of its potential to assess the entire body simultaneously addressing more features (than OWAS or RULA) of posture like static and dynamic postural loading factor, human-load interface and gravity assisted upper limb position which are important factors for the study. In REBA, the baseline posture is anatomically neutral. As the posture moves away from the neutral position, the risk scores increase. Tables are available to transform 144 posture combinations into a single score that represents the levels of musculoskeletal risk [37]. These

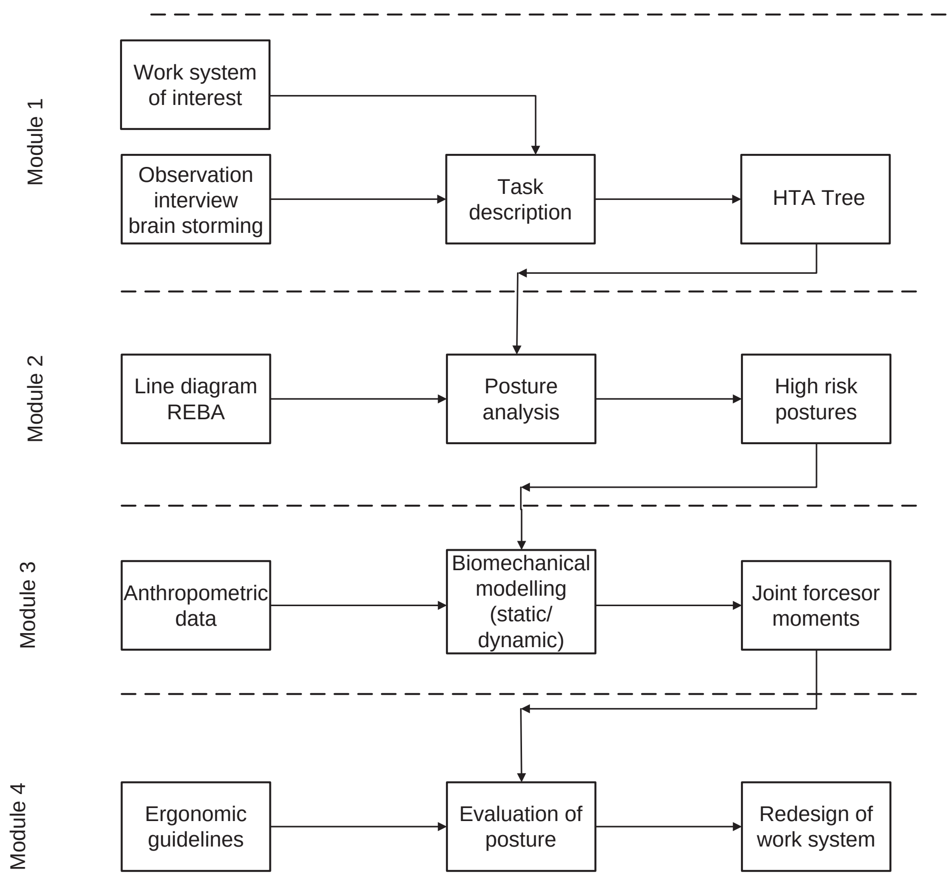

Fig. 1: A flow chart showing the proposed methodology.

scores are then banded into five action levels that advise on the urgency of avoiding or reducing the risk of the assessed posture.

3.3. Biomechanical Modeling

Module III involves biomechanical modeling. Within the context of the overall framework, posture analysis based on recorded video can be used for filtering physically high-risk task, and biomechanical analysis can be used further for those tasks that are found to be high-risk task by the posture analysis. In this methodology, dynamic top-down approach of modeling is used which is based on Chaffin's link segment model [4]. For biomechanical evaluation, the model can be classified into static where acceleration component is ignored or dynamic where acceleration component is considered. Further, the biomechanical modeling approach can be (i) top-down approach where, calculation of joint forces and moments begin from wrist and proceed downwards and (ii) bottom-up approach where the corresponding calculations begin from the foot and progress towards the upper part of the body. Static link-segment human models can be obtained from photographs or video frames of human postural activity, while dynamic link-segment human models can be obtained from video or sensor based motion capture systems.

In this case-study (see Section 4.3), high risk postures (through video) and anthropometry of the exposed population (by measurement) are the inputs to the biomechanical model, and output is restricted to L5/S1 compressive loadings.

3.4. Digital Human Modeling

Module IV in the proposed methodology involves computerized redesign by DHM. The human mannequin model is based on anthropometric data and the work system model is based on the design specifications given. Some examples of software that use human mannequin are SAMMIE, BOEMAN, JACK, Anybody, SANTOS, HumanCAD, RAMSIS, SAFEWORK. Working model simulation of the task depicts not only the human motion but also the man-machine interactions. An iterative evaluation based on participative inputs by ergonomist and maintenance engineer against guidelines like NIOSH limits or joint tolerances shall ultimately lead to feasible redesign options to reduce the man-machine incompatibility.

4. CASE STUDY

The current case study attempts to integrate HTA framework for maintenance task analysis and supports the observational based DHM methodology to undertake ergonomic evaluation and redesign.

The study was conducted in the maintenance section of a department in an integrated steel plant situated in eastern India. The job involves maintenance of the billet mould and is carried out on a workstation called trestle. Informed consent for the procedures and data collections was obtained from company management prior to actual data collection, and consent of the workers was also obtained. The job requires positioning the mould on the trestle, disassembling it for repair and then reassembling the subcomponents. The repaired mould is subsequently sent into caster. Each day 1 - 2 such repairs are undertaken. The job is carried by 2 workers together in a shift (3 shifts a day). The approximate time to complete the maintenance task is 4 – 5 hours. For moving heavy parts an overhead crane is used. Tools and accessories used during the maintenance include a mallet, a tackle and spanners. Though heavier components are handled by overhead crane, there is considerable physical exertion during the operations. The workers have complained of discomforts and stress on elbow, shoulder and lower back. The general layout of the workplace is given in Fig. 2.

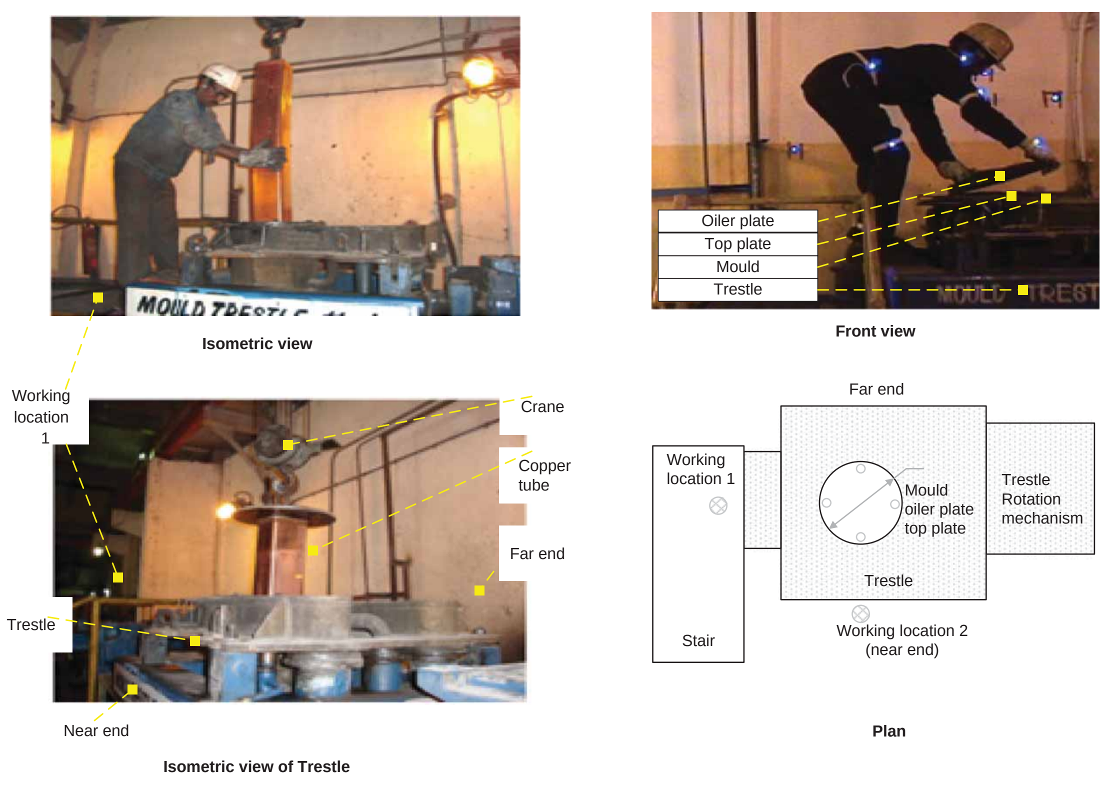

Fig. 2: Workplace layout of trestle.

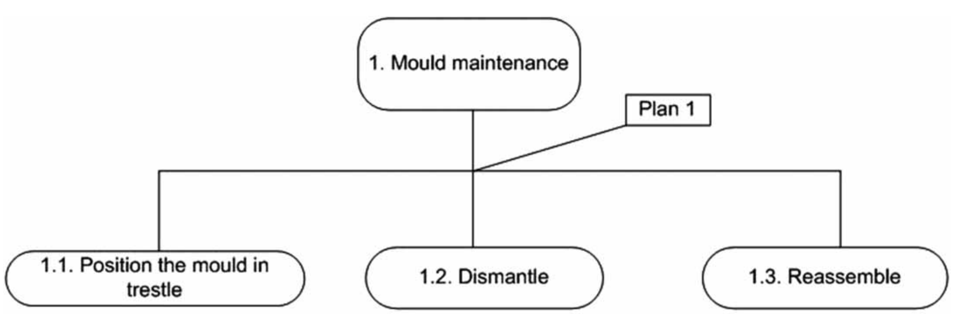

Fig. 3(a): Hierarchical task-tree for billet mould maintenance.

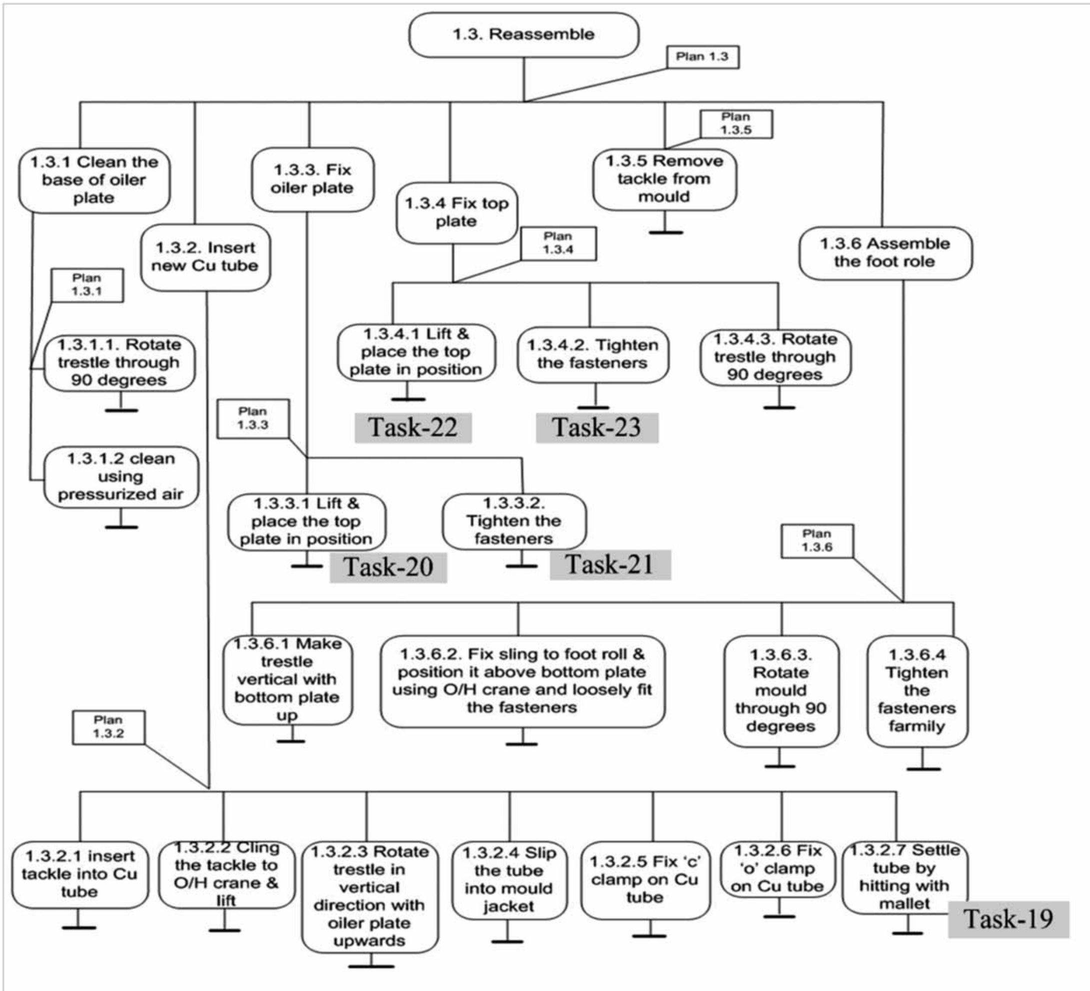

Fig. 3(b): Hierarchical Task Tree – Sub-tree 3.

Fig. 4: Working posture for task-16.

4.1. Hierarchical Task Analysis

Following the brief introduction of HTA, its aims and rationale, the engineers and the workers were asked to describe their jobs in terms of its sub-task operations and plans. The data were obtained by means of unstructured interviews with two junior engineers (supervisors) and three workers who have experience ranging from two years to ten years. The interview data were supplemented by direct observations on the job. A total of 29 such tasks are identified (Tab. 1). The hand forces were measured using hand dynamometer after the experiments were conducted. For illustration two HTA trees are shown in Fig. 3(a)., and Fig. 3(b). Figure 3(a) shows top-level Hierarchical task-tree for billet mould maintenance. Figure 3(b) shows the HTA of '1.3 Reassemble' component of billet mould maintenance.

HTA has given elaborate task description bringing in clarity to the task elements at each hierarchical

Task No.	Description	Task type@	Frequency	Duration %	Force applied	HTA code	REBA Score
1	Shift mould from mould stand to transfer trolley with the help of overhead crane & jib crane.	p	2	10	NA	1.1.1	0
2	Keep the mould in the trestle and fix it in position by tightening the nuts.	m	2	1	Neg	1.1.2	6
3	Rotate the trestle though 180° using the control.	p	2	2	NA	1.2.1.1	0
4	Fix sling to the foot roll.	m	2	3	Neg	1.2.1.2	2
5	Open the nuts (4 nos) and remove the foot roll by crane.	m,p	4(32)	5	380	1.2.1.3	5
6	Rotate the trestle by 90°.	p	1	1.5	NA	1.2.2.1	0
7	Dismantle the top plate using spanner (4 nos) and let the plate drop.	m	4(32)	2	280	1.2.2.2	2
8	Dismantle the oiler plate using spanner (4 nos) and let the plate drop.	m	4(32)	2	280	1.2.3.1	6
9	Insert the tackle to remove the copper tube and make the trestle vertical.	m	1	5	Neg	1.2.4.1	6
10	Dismantle the copper tube by crane.	p	1	10	NA	1.2.4.2	0
11	Rotate through 90°.	p	1	1.5	NA	1.3.1.1	0
12	Clean the top plate and oiler plate.	m	1	10	Neg	1.3.1.2	2
13	Insert the tackle to new copper tube.	m	1	1	Neg	1.3.2.1	2
14	Hold the tackle in winch hook with new copper tube.	p	1	1	NA	1.3.2.2	0
15	Rotate the trestle in vertical direction such that base for oiler plate is upwards.	p	1	1.5	NA	1.3.2.3	0
16	Fixing of new copper tube in mould jacket.	m,p	1	15	Neg	1.3,2.4	2
17	Fixing of ‘C’ clamp on new copper tube.	m	1	1	Neg	1.3.2.5	2
18	Fixing of ‘O’ ring at top of the copper tube.	m	1	1	Neg	1.3.2.6	5
19	Settle the tube by hammering with a soft hammer (mallet).	m	1(10)	2	80	1.3.2.7	9
20	Place the oiler plate in position.	m	1	2	200	1.3.3.1	8
21	Fasten the oiler plate bolts (4 nos).	m	4(32)	5	380	1.3.3.2	8
22	Place the top plate in position.	m	1	2	250	1.3.4.1	8
23	Fasten the bolt of the top plate (4 nos).	m	4(32)	5	380	1.3.4.2	8
24	Rotate the trestle such that the bottom plate faces the worker.	p	1	1.5	NA	1.3.4.3	0
25	Remove the tackle from the mould.	m	1	1	Neg	1.3.5	3
26	Rotate trestle thorough 90 °.	p	1	1.5	NA	1.3.6.1	0
27	Position the foot role above the mould and loosely fit the fasteners.	m,p	1	3	Neg	1.3.6.2	2
28	Rotate trestle through 90°.	p	1	1.5	NA	1.3.6.3	0
29	Firmly bolt the fasteners (4 nos) on the vertical plane.	m	4(32)	5	380	1.3.6.4	6

@ *p* stands for powered, *m* stands for manual; # Frequency is the number of times the task is executed and number of physical exertions in bracket; % Duration is in minutes; * Force values are based on feedback from worker. Force is in *N*. Force ‘*NA*’ indicates none, ‘*Neg*’ indicates use of less force (< 50N).

Tab. 1: HTA of billet mould maintenance.

Group No	Steps**	REBA Score	Severity	Action
1	1, 3, 6, 10, 11, 14, 15, 24, 26, 28	0*	No	None Necessary
2	4, 12, 13, 16, 17, 27	2	Low	None Necessary
3	9, 25	3	Medium	May Be Necessary
4	5, 18	5	Medium	May Be Necessary
5	2, 7, 8, 29	6	Medium	May Be Necessary
6	20, 21, 22, 23	8	High	Necessary Soon
7	19	9	High	Necessary Soon

*A risk score of zero here implies that no direct human involvement is present; ** Task number and corresponding HTA code is provided in Tab. 1.

Tab. 2: REBA scores for the 29 tasks identified.

level. Apart from the clarity provided for better REBA analysis, HTA has enabled to pinpoint start and end of actions that are relevant for biomechanical analysis in terms of the appropriate selection of frame segments from the overall video.

4.2. Posture Analysis

The working postures of the 29 tasks were photographed. The line diagram of task-16 is shown in Fig. 4. The 29 tasks identified (Tab. 1) were analyzed using REBA. The REBA scores are given in Tab. 2. The five high severity tasks shown in Fig. 5 require immediate actions for improvement. Biomechanical analysis is conducted next for the five 'high risk' based on on-field observational video recordings of the tasks.

Posture analysis of the 29 tasks using REBA found 5 tasks namely (i) task 19 - striking with mallet, (ii) task 20 - positioning oiler plate, (iii) task 21 - fastening oiler plate, (iv) task 22 -positioning top plate, and (v) task 23 - fastening top plate, to be under 'high severity' category indicating the need for immediate attention or further assessment. Based on HTA plus REBA results two branches are visibly on the high risk side i.e branches with HTA code 1.3.3 and 1.3.4 (see Fig. 3(b)). Herein, the tasks 20 and 22 are characterized by intense forward bending combined with heavy lifting (20 / 25 kg); and the tasks 21 and 23 is characterized by intense forward bending along with high external force (380 N) applied on the handle of the wrench for fastening. The oiler plate and top plate are handled by overhead crane in moving from ground level to trestle level for assembly, but final positioning is manually handled (tasks 20 & 22) with awkward posture. For task-20 and task-22 the size of the oiler plate is 45Ø cm and top plate is 41Ø cm, and the weight is 20 and 25 kg, respectively. The size is not large and can be grasped and held properly but the weight is high. Task 19 is characterized by intense forward bending and lifting above shoulder. The weight of oiler plate and top plate is a possible source of lower back MSD risk.

Fig. 5: Working postures for five high risk tasks (19 – 23).

HTA plus REBA results indicate that all the tasks in sub-trees 1.1 and 1.2 have a REBA score 0 – 6. Though sub-trees 1.1 and 1.2 do have external forces being applied, it is moderated by the standing posture as compared to flexed posture for the sub-tree 1.3. Since for all the above cases posture has a significant role, our efforts to redesign the workstation from postural angle seems justified.

4.3. Biomechanical Modeling

For the biomechanical analysis, 3 male workers (average age: 29 years, average weight: 57.8 average height: 1.68 m and average experience: 24 months) participated in an onsite video based study. Three trials for each task were recorded with at least 3 minutes of rest in between. A S-VHS camcorder (Sony DCR-HC62) with a sampling frequency of 60 Hz, was positioned at a distance of 4.98 m from the proximal end of the trestle and the camera with optical axis being perpendicular to the Sagital plane of the worker was placed parallel to the ground. Self illuminated LED markers were used for collection of motion data. Fig. 5 shows photographs of the video based study of the 5 high risk tasks i.e., (i) task-19 (settle the tube by hammering with a soft hammer), (ii) task-20 (place the oiler plate in position), (iii) task-21 (fasten the oiler plate bolts), (iv) task-22 (place the top plate in position), and task-23 (fasten the bolt of the top plate). The motion pictures so obtained were digitized using Ariel Performance Analysis System (APAS) to obtain the required kinematic data for body joints. The digitized data were filtered (smoothened) using Quintic algorithm. For lifting force in tasks 19, 20, and 22, the weights (in kg) of the mallet, oiler plate, and top plate were used and for fastening tasks (number 21 and 23), the forces were measured by hand dynamometer.

In the context of the case study the biomechanical evaluation is focused on lower back. Tab. 3 summarizes the biomechanical loading on L5/S1, and the frame-wise biomechanical loadings on L5/S1 are shown in Fig. 6. In DHM (section 4.4) the redesigned worksystem is evaluated by JACK that uses 3400 N as the action limit. Biomechanical evaluation quantified the mechanical exposure on lower back for those five high risk tasks. From biomechanical perspective, the tasks 19, 20 and 22 cause compressive loadings on the lower back, while the tasks 21 and 23 cause lateral shear loadings in addition to compressive forces on lower back. For example, Fig. 6(c) and Fig. 7(c) shows the compressive and lateral-shear forces bar chart for tasks 19 and 21. Lower back compressive forces in terms of range, mean and peak forces through static biomechanical analysis were 2948 – 5707, 3854(sd-741) and 4515 (sd-821) N respectively. Lower back compressive forces in terms of range, mean and peak compressive forces through dynamic biomechanical analysis were 4069 – 5701, 3973 (sd-651) and 4756 (sd-523) respectively. So, considering the L5/S1 strength range of 2300 – 6000 N, a large percentile of people will suffer from lower back disorders. Task-19 distinguishes from other high risk task because of the presence of dynamic component in the task. Fig. 6(a)., and Fig. 6(b) highlight the static as well as dynamic components in the Tasks 19 and 20, respectively. The results as obtained are comparable to the L5/S1 compressive loadings of 1500 – 5000 N based on static [42] and dynamic modeling [14] for the weight range from 67 – 256 N. The biomechanical analysis has confirmed the need for intervention for the five tasks by objective measures of L5/S1 compressive loadings. Intervention to alleviate Task-19 related problem could be looked at from the dynamic component in the assembly task, while the tasks 20 - 23 could be approached from improved posture.

		Static Analysis		Dynamic Analysis	
Task No	Worker	Mean (Std)	Peak	Mean	Peak
19	1	2766 (137)	2948	2998 (503)	4121
	2	3264 (137)	3400	3534 (730)	4531
	3	3241 (307)	3445	3504 (924)	4871
20	1	3716 (310)	4091	3674 (237)	4069
	2	4052 (358)	4492	4016 (282)	4480
	3	3035 (1098)	4386	3045 (1017)	4432
21	1	4675 (258)	5025	4710 (231)	5046
	2	2966 (197)	4200	3972 (438)	4181
	3	4916 (1179)	5381	4927 (1087)	5412
22	1	3846 (291)	4245	3826 (197)	4232
	2	3621 (231)	5163	3608 (219)	5030
	3	3608 (294)	5163	3621 (277)	5030
23	1	4787 (540)	5707	4805 (482)	5701
	2	4342 (233)	4595	4371 (256)	4717
	3	4972 (298)	5487	4992 (279)	5492

Tab. 3: Biomechanical Loading on L5/S1 (N) for the five high risk tasks.

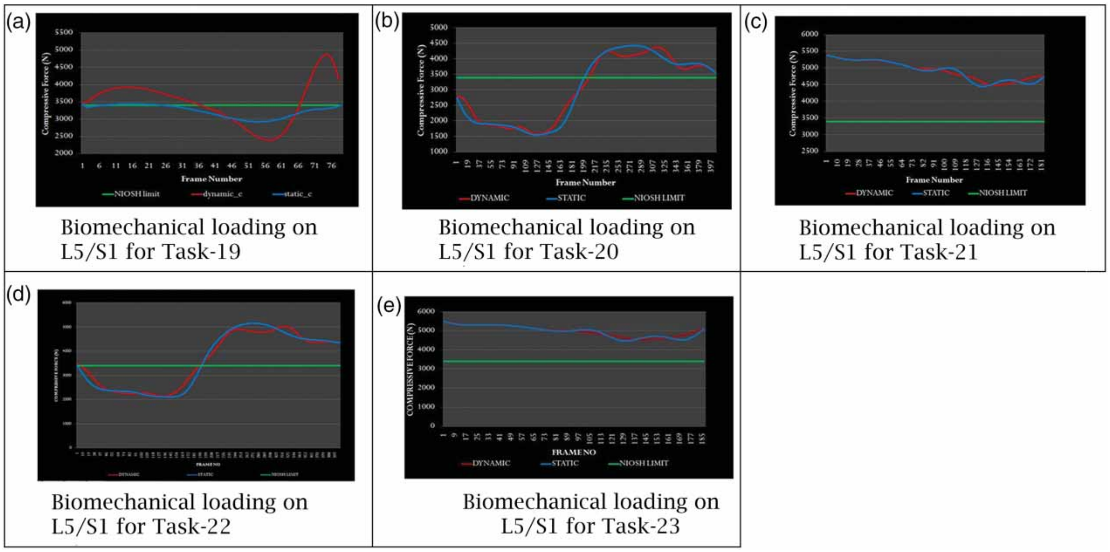

Fig. 6: Biomechanical loading on L5/S1 for five high risk tasks (19 – 23).

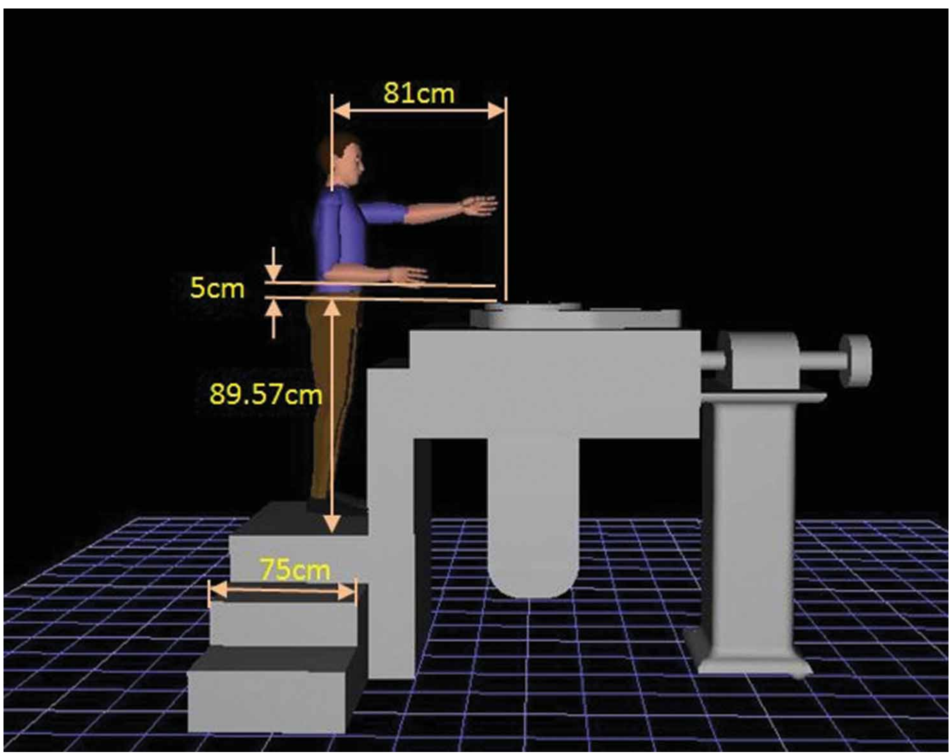

Fig. 7: Redesign of workstation (Trestle).

The possible alternatives for redesign could be (i) use of mobile stair at far or near end, (ii) use of hydraulic wrench/spanner (gun shaped), (iii) modification of mallet (by reducing weight), and (iv) modification of stair/platform. A discussion about the intervention solution was discussed with the shop-floor engineers and workers. The intervention options (i) was constrained by space, (ii) and (iii) was constrained by inconclusive positive feedback from workers and infeasibility of on-field/DHM testing of fastening alternatives, and (iv) was favorably perceived by shop-floor engineers and workers. Based on the discussions on the alternatives (i) to (iv), it was decided to undertake redesign of the working platform.

4.4. Digital Human Modeling

For redesigning of the working platform, DHM by JACK software is used. The anthropometric data of the workers were taken before undertaking the DHM exercise. For the redesign, first the causes of the man-machine mismatch are identified. Reduction of L5/S1 compressive forces is undertaken based on changes in postural and workstation dimensions. A new design is proposed in which the worker stands on the platform while working on the trestle, so as to reduce the flexion on the part of the worker. The height of the top most surface of trestle from the standing platform is the elbow height of the worker plus admissible allowance. The new design must become suitable for the larger population of workers. So, we have chosen the elbow height at the 5th percentile (plus an allowance of 5 cm) and the reach distance at the 5th percentile of the working population in that region. The new design with dimensions is shown in Fig. 7. Now the 5 'high risk' tasks are assessed with the help of human mannequin created in JACK. The human mannequin is modeled for proposed design and compared with current design. Fig 8(a)., and Fig. 9(a) show the DHM of task-19 and task-21 in the current worksystem, while Fig 8(b)., and Fig. 9(b) shows the same for proposed system. Fig 8(c)., and Fig. 9(c) show the results of evaluation done in JACK.

Finally through DHM, a new design is obtained. Within the constraint imposed, we have given a less optimal but feasible design solution. In the new design the standing platform is lowered by 41 cm. The postural change and compressive loadings on L5/S1 for the 5 high-risk tasks are assessed using JACK lower-back analysis module. Distance of forward reach is now 81 cm and the forward flexion of the back is reduced to 5 - 10° from 45 - 80°. For the redesigned condition, the L5/S1 loadings for the tasks 19, 20, 21, 22, and 23 are 2637 N, 2010 N, 2349 N, 2323 N and 2333 N, respectively. The net effect as deduced from the DHM is a lowering of compressive force at L5/S1 from 2948 - 5707 N to 2010 - 2637 N. This redesign has effectively reduced the lower back loadings and therefore reduces the risk of MSD to lower back of the worker. One of the limitations of the new design is that it accounts for height related postural stress and not the reach related postural

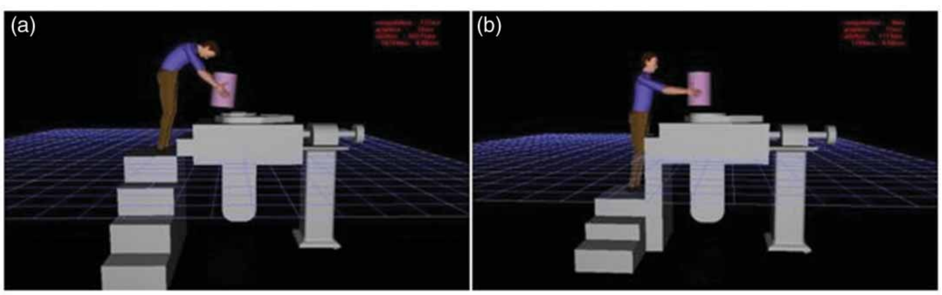

Fig. 8: (a) and (b) Posture adopted by the worker while performing the task-19 on old and redesigned trestle.

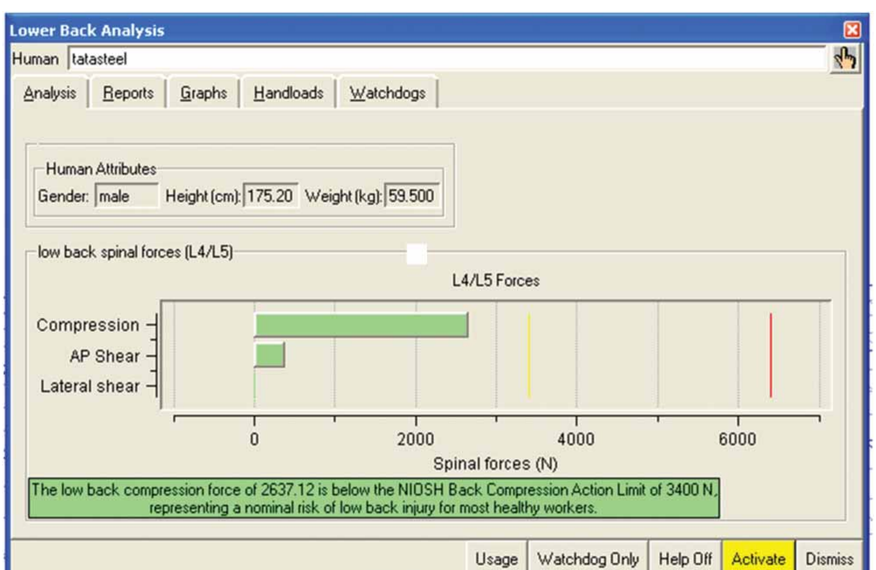

Fig. 8: (c) Result of evaluation done on JACK displaying compressive force on L5/S1 for the task 'striking with mallet' for posture in 6(b).

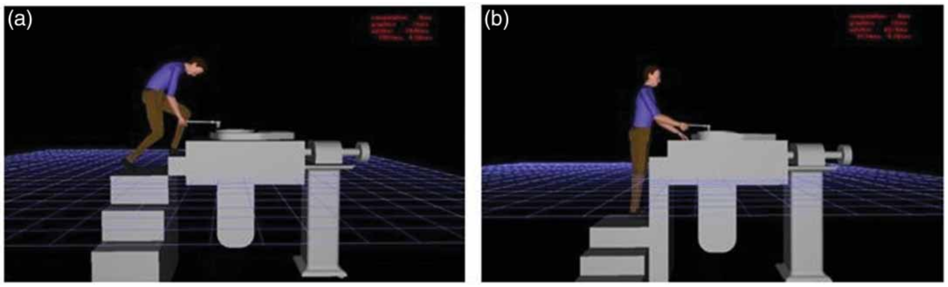

Fig. 9: (a) and (b) Comparative posture adopted by the 95th percentile worker while performing the task 'fastening of oiler plate' on old and redesigned trestle.

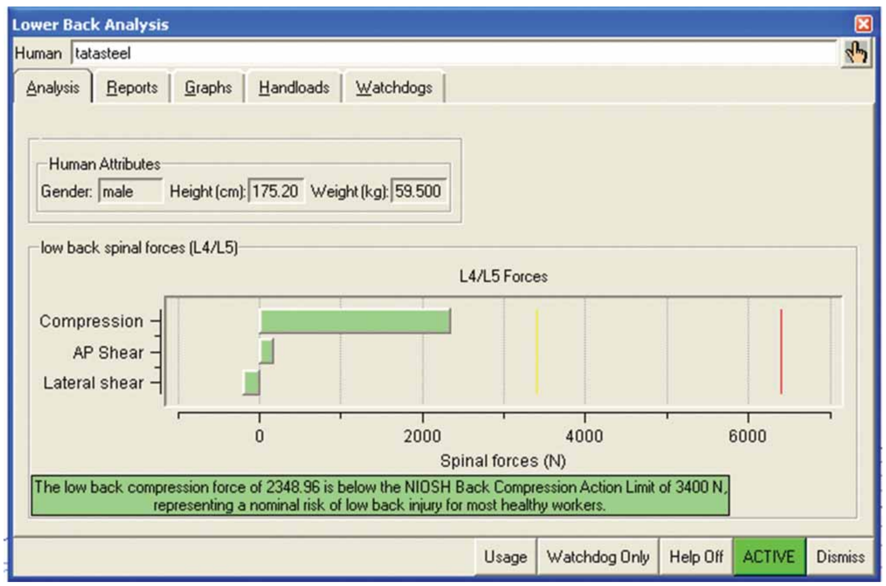

Fig. 9: (c) Result of evaluation done on JACK displaying that compressive force on L5/S1 for the task 'fastening of oiler plate' for posture in 7(b).

stress due to the feasibility of interventions stated earlier. Nonetheless a positive postural change has been observed due to the redesign.

5. LIMITATIONS

This may be one of the first observational studies in India where a manufacturing organization has agreed to such a study. However a few constraints and limitations are highlighted here. The biggest limitation was undertaking the data collection for the biomechanical analysis in a practical field setting. Secondly, the experiment was not designed to capture lateral shear forces on L5/S1 and shoulder joint loads. Thirdly, dynamic component of biomechanical forces and moments are ignored in this study.

In the current study, motion capture was through a single video camera. Therefore, motions in sagital plane (e.g., Figure 5) can be effectively observed. The limitations is that (i) true 3D dynamic analysis was not possible for lack of 6-12 video streaming (i.e., synchronous and calibrated) in the industrial environment, (ii) since the actual motions involved 3D postural manoeuvring, there is possible inaccuracies in the biomechanical values obtained.

There is a dearth of tools or techniques that can be effectively used for biomechanical exposure measurement & estimation for field environment [33]. Video based study is still the commonly used method of quantifying biomechanical exposure. The work of Diego-Mas and Alcaide-Marzal [9] is one such example where kinect sensor was used for motion capture. Nonetheless the study provides leading indication to design change, and trying to focus on biomechanical modelling or methodological issues is beyond the scope of the study undertaken.

6. CONCLUSIONS

The study provides an efficient approach for description of the tasks through HTA, followed by screening out of trivial tasks through postural analysis, objective quantification of physical exertion through biomechanical modeling and redesign of worksystem through DHM. The advantage of using the proposed methodology is that a clear task description helps the analysis of postures in totality that prioritizes high risk postures for objective modeling such as biomechanical modeling. The biomechanical analysis specifies the type of interventions needed. For example for task-19 intervention is required to alleviate the problem related to dynamic component in the assembly task whereas for the tasks 20 to 23, intervention is needed to improve posture. When such ergonomically poor designs are made visible and alternate designs proposed, it is all the more likely to be accepted by the management and taken up for intervention. The results and benefits of the test case were appreciated by the Management.

The design solutions were not implemented at the time of study due to production related issues. The study can be improved to ascertain the total risk of the job by capturing 3D dynamic components of the physical exertion and by accurate measurement of the input forces.

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