Evaluation of a Harmony Search Algorithm for Manual Lifting Tasks Optimization

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ABSTRACT

This paper presents near optimal solution method to find safe work place design using harmony search algorithm. Revised NIOSH equations are considered to minimize relative estimate of the physical stress associated with a manual-lifting job. The proposed algorithm will assist occupational safety and health practioners in evaluating lifting tasks and reducing the incidence of low back injuries in workers.

General Terms

Algorithms, Heuristics, Ergonomics, Work Design.

Keywords

Lifting, Harmony Search Algorithm, Workplace, Design.

1. INTRODUCTION

Manual work design is the process of designing work according to human capabilities and limitations. Lifting processes as manual work have commonly variety of postures problems that always considering the pressures on the musculoskeletal system. Low back injuries are common and frequent health problems for many workers who lift materials [1], [2]. Low back pain occurs generally as a result of incorrect and bad lifting methods. Its frequency is associated with lifting repetition, bending and twisting motions of the torso [3]. It can be considered as an expensive health problem for employees because of paying not only for workers' compensation, but also spending more on tests, treatments, claims, and surgeries [4], [5]. In general; job physical factors, worker demographics, past low back pain history, psychosocial factors, hobbies, and physical activities outside of work can be listed as main causes of low back pain [6], [7]. There are several studies including associations between job physical factors and [1], [8]–[10].

National Institute of Occupational Safety and Health developed NIOSH Lifting Equation to evaluate two-handed lifting tasks in 1981 and revised in 1993. The equation was designed to assist in the identification of ergonomic solutions for reducing the physical stresses associated with manual lifting. The revised NIOSH Lifting Equation commonly used to quantify biomechanical stressors to low back from lifting and lowering of materials [11]–[15]. The revised equation evaluates two main parameters, Recommended Weighted Limit (RWL) and Lifting Index (LI), to determine the safety level of lifting procedure [16], [17].

Manual lifting problem can be explained with RWL and LI and especially at the lifting design level, but unfortunately, even in its simplest forms, it is an intractable NP hard optimization problem. Exact methods can be rarely adopted and, for problems of practical interest, the idea of global optimization must be abandoned in favour of the search of good and feasible solutions.

Concerning the solution approach, since the problem is NP hard, a novel meta-heuristic is proposed based on the Harmony Search (HS), a recent algorithm in the family of the population based evolutionary heuristics [18], which has proven its effectiveness in solving NP-hard combinatorial problems [19]. The algorithm's global search capabilities are evaluated using a previously published suite of difficult analytical genetic algorithm test problems [5] while its sensitivity to lifting design variables scaling is given mathematically by NIOSH and verified using various lifting conditions. For both categories of problems, HS robustness and performance are compared to genetic algorithm (GA). This study contributes to a better understanding of the revised NIOSH Lifting Equation applied to field conditions by providing a detailed description of the procedures for measuring its variables.

The paper is structured as follows. Section 2 introduces the basic notation and gives full details concerning the recommended weight limit and lifting index for manual lifting problem. The meta-heuristic used to find an optimal solution is explained in Sections 3 and it is validated in Sections 4. To this aim a comprehensive set of manual lifting problems is generated and solved, using as benchmark two alternative heuristics (purposely developed to this scope) and a recent genetic algorithm developed by Carnahan and Redfern (1998) [11]. Lastly, conclusions and directions for future works are given in Section 5.

2. PROBLEM FORMULATION

2.1 Recommended Weight Limit (RWL)

The RWL is the principal product of the revised NIOSH lifting equation. There are many factors that can affect a lifting operation and it is important that personnel involved in lifting operations are aware of such factors. These factors are Load Weight (L); Weight of the object to be lifted, Horizontal Location (H); Distance of the hands away from the mid-point between the ankles, Vertical Location (V); Distance of the hands above the floor, Vertical Travel Distance (D); Absolute value of the difference between the vertical heights at the destination and origin of the lift, Asymmetry Angle (A); Angular measure of how far the object is displaced from the front (mid-sagittal plane) of the worker's body at the beginning or ending of the lift, Neutral Body Position; the position of the body when the hands are directly in front of the body and there is minimal twisting at the legs, torso, or shoulders. The asymmetry angle is defined by the location of the load relative to the worker's mid-sagittal plane, as defined by the neutral body posture, rather than the position of the feet or the extent of body twist, Lifting Frequency (F); Average number of lifts per minute over a 15 minute period, Lifting Duration; Three-tiered classification of lifting duration specified by the distribution of work-time and recovery time,

Coupling Classification; Classification of the quality of the hand-to-object coupling quality is classified as good, fair, or poor, and finally Significant Control; A condition requiring precision placement of the load at the destination of the lift. This is usually the case when the worker has to re-grasp the load near the destination of the lift, or the worker has to momentarily hold the object at the destination, or the worker has to carefully position or guide the load at the destination [16].

RWL is equal to multiplication of load constant, horizontal multiplier, vertical multiplier, distance multiplier, frequency multiplier, asymmetry multiplier and coupling quality multiplier (Eq. 1).

$$RWL = LC \times HM \times VM \times DM \times FM \times AM \times CM \quad (1)$$

Where;

LC: Load Constant = 23 kg,
HM: Horizontal Multiplier,
VM: Vertical Multiplier,
DM: Distance Multiplier,
AM: Asymmetric Multiplier,
FM: Frequency Multiplier,
CM: Coupling Multiplier,

Also, the values of these multipliers can be computed as LC is equal to 23 kg, HM is equal to (25/H), VM is equal to $1 - (0.003|V-75|)$, DM is equal to $0.82 + (4.5/D)$, AM is equal to $1 - (0.0032A)$, FM and CM are taken from lookup tables in NIOSH reference guide [16] or one can directly get all them from lookup tables in NIOSH [16].

2.2 Lifting Index (LI)

Before discussing the standardized goodness, the importance and meaning of Lifting Index (LI) have to be clearly explained. It is a term that provides a relative estimate of the level of physical stress associated with a particular manual lifting task and equals to load weight divided by RWL (Eq. 2) [16].

$$LI = (W_t) / RWL \quad (2)$$

There are several studies which conclude that lifting tasks with a Lifting Index greater than 1.0 pose an increased risk for lifting-related low back pain [1], [3], [7], [16], [17], [20]. The greater LI is, the more LBP risk occurs. Any increase of LI causes increase of the level of the risk for the worker. Thus, a greater percentage of workforces are likely to be at risk for developing lifting-related low back pain. Therefore, the goal should be to design the lifting jobs to achieve a LI of 1.0 or less.

The manual lifting problem has design parameters of workspace. The environmental conditions are established by setting the constraints on the solutions. These are weight of the load handled (kg), Quality of the handle interface (good, poor, fair), The number of lifts needed for one operator, Minimum and maximum allowed time to perform the lifts and an acceptable Lifting Index (LI) determined by ergonomist. The first and the second environmental parameters are constraints of lifted load. The third and the fourth environmental parameter constitute demands of lifted load and an acceptable Lifting Index (LI) gives the safety concerns of the ergonomist.

Horizontal distance from load to ankles, asymmetric angle between load and sagittal plane, vertical distance of hands from floor-end to lift, vertical distance of hands from floor-start to lift, and duration of lifting procedure are used as design parameters of the manual lifting problem. The

acceptable and operational limits of these parameters determined by NIOSH (1994) are given in Table 1. All these design parameters were evaluated by Harmony Search algorithm and two types of goodness function, Recommended Weight Limit as Raw Goodness and Standardized Goodness, was considered as fitness value. These are quantifiable measures of how well the solution meets the productivity and safety constraints that comprise the environment conditions for lifting design problem.

Table 1. Design parameters of evaluated lifting problem

Parameter	Definition	Min.	Max.
H	Horizontal distance (load to ankles)	25.4 (cm)	63.5 (cm)
A	Asymmetry (between load and sagittal plane)	0 (deg)	135 (deg)
V_e	Vertical distance (hands to floor-end to lift)	0 (cm)	177.8 (cm)
V_s	Vertical distance (hands to floor-start to lift)	0 (cm)	177.8 (cm)
D	Duration of lifting task	Min (h)	Max(h)

3. HARMONY SEARCH ALGORITHM

3.1 Basic Features

There are many different optimization techniques to solve lifting design problems [21]. While gradient-based nonlinear programming is the most widely used one, it may become difficult and unstable when the objective function and constraints have multiple or sharp peaks [19]. A successful strategy, a Genetic Algorithm, was suggested to get more than suitable solutions for lifting design problems by Carnahan and Redfern [11]. In the same objective, Harmony Search algorithm was selected to evaluate adjustable lifting designs.

There are several studies considering that music is a satisfying processes in shopping, education, productivity for workers, and even in surgery process [22]–[27]. This inspired Geem et. al. [18] to produce a new heuristic algorithm derived from an artificial phenomenon found in musical performance. While musical performances seek a best harmony by using different instruments and written music, the optimization algorithms seek a best state (global optimum - minimum cost or maximum benefit or efficiency) determined by objective function evaluation [18]. The harmony in music can be thought as the optimization solution vector, and the musicians' improvisations are similar with local and global search schemes in optimization techniques [19]. The advantages of Harmony search can be listed as follows;

- It does not require initial values,
- It uses a stochastic random search so that derivative information is unnecessary,
- It needs fewer mathematical requirements than other heuristics/meta-heuristics,
- It can be easily adopted for various types of engineering optimization problems.

Recent studies show its implementation capability to different type of optimization problems. Sabar and Kendall [28] used it to select portfolio, Gao et. al. [29] proposed a job shop

scheduling problem, and Maheri and Narimani [30] used it in a design problem of side sway steel frames. These examples can easily multipliable by searching current literature. In the light of all these positive characteristics of Harmony Search algorithm is a competitive method to find optimal work designs in lifting problems.

Table 2. The behavior while playing music versus harmony search (Lee and Geem, 2005)

Playing Music	Harmony Search
Playing any one pitch from his (or her) memory	Choosing any one value from the HS memory
Playing an adjacent pitch of one pitch from his (or her) memory	Choosing an adjacent value of one value from the HS memory
Playing totally random pitch from the possible sound range	Choosing totally random value from the possible value range

The behavior of a musician can be summarized as in Table 2. It can be seen that the similarity between music playing procedure and optimum point searching procedure of Harmony Search. The main steps of Harmony Search are as follows [19]:

- Initialize the optimization problem and algorithm,
- Initialize the harmony memory (HM),
- Improvise a new harmony from HM.
- Update the HM,
- If stopping criteria are not satisfied, go step ii.

Fig.1. Structure of Harmony Memory (Geem et al., 2001)

Figure 1 gives the main Harmony Memory structure. There are three instruments as of fiddle, saxophone, and keyboard. Initially, all instruments have their memories with random harmonies (step ii): (C, E, G), (C, F, A), and (B, D, G) that are sorted by aesthetic estimation. In step iii, three instruments produce a new harmony; for example, (B, E, G): fiddle sounds {B} out of {C, C, B}; saxophone sounds {E} out of {E, F, D}; and keyboard sounds {G} out of {G, A, G}. This procedure is an equally random selection from HM of each instrument with a probability of 33.3% for any note. Step iv suggests the updating HM with better results. If the new harmony (B, E, G) is better than any of the existing harmonies in the HM, the new harmony is included in HM and the worst harmony (in this example, (B, D, G)) is excluded from the HM. Then the termination criteria are checked to stop algorithm (step v).

Harmony Search algorithm has two main parameters, Harmony Memory Consideration Rate (HMCR) and Pitch

Adjusting Rate (PAR) which get values between 0 and 1. HMCR is needed in the case that all optimum decision parameters do not exist initially in HM. If a uniformly generated value between 0 and 1 occurs above the HMCR, then Harmony Memory finds notes randomly within the possible playable range without considering HM [18]. The PAR is introduced to escape local optima and mimics the pitch adjustment of each instrument. It works by shifting to neighboring values within a range of possible values. If there exist five possible design variables such as {2, 7, 5, 8, -4}, {5} can be moved to neighboring {7} or {8} in the pitch adjusting procedure [18]. These parameter are generally set as HMCR is between 0.7 and 0.9, PAR is between 0.1 and 0.5 [31].

3.2 Proposed Algorithm

Environmental conditions of the lifting problem can be considered as task requirements so that the Harmony Search could generate new design solutions. This algorithm finds alternative solutions, with a number of Harmony Memory size, within environmental conditions. The evaluation stages of the Harmony Search algorithm are given as follows;

- Initialize the optimization problem and algorithm,

Harmony Search algorithm searches optimal design parameters for lifting that will meet the environmental conditions. So, all environmental conditions must be determined at the beginning. In this study, the load weight (Kg), handle interface of the material, number of lifts, lifting time range (hour), and Lifting Index was determined as environmental conditions (Table 2).

- Initialize the harmony memory (HM),

Harmony Search algorithm randomly generates 200 variable design solutions, which is the Harmony Memory Size, within given limits as in Table 1. Each solution is a linear array of five real numbers. This array shows five constraints for lifting workplace design.

Randomly generated three harmonies can be seen in Table 3. In this stage, Harmony Search evaluates goodness for all HM.

- Improvise a new harmony from HM.

A new harmony is generated by considering HMCR and PAR. The goodness of new harmony is evaluated.

- Update the HM,

If the new harmony is better than any of existing one, it is added to HM and the worst one is removed from HM.

- If stopping criteria are not satisfied, go step ii.

The stopping criterion for this study is reaching a maximum iteration number which is set 2500.

Table 3. Example of an initial randomly generated three harmonies in harmony memory

Harmony	H (cm)	A (deg)	Ve (cm)	Vs (cm)	D (h)
1	30.7	2	41.1	127.2	115.3
2	22.5	105.7	85.9	17.7	109.5
3	27.6	3.8	95	64.3	30.6

3.3 Test Problems

The lifting process may have different physical conditions according to the lifting object, productivity plans, and

workplace limitations. In this study, six different work environments in the current literature [11] were considered to find optimal design parameters (Table 4). These conditions are common work environments with a variety of production demands and lifting indices and can be summarized as follows;

Table 4. Test problems (Carnahan and Redfern, 1998)

Env.	Weight (Kg)	Coupling Quality	Number of lifts	Duration (h)	LI
Con.1	9.0927	Good	600	0.0 - 2.0	1.0
Con.2	4.5463	Poor	200	0.0 - 0.6	1.0
Con.3	18.1447	Poor	900	3.0 - 8.0	2.0
Con.4	31.8042	Good	300	0.0 - 8.0	2.0
Con.5	47.7064	Fair	100	0.3 - 3.3	3.0
Con.6	5.4332	Fair	2400	4.0 - 8.0	1.0

Condition 1: The lifted load has a moderate weight with 9.0923 kg. It has a good handles. 600 lifting are required for a worker. The lifting duration must be in the range of 0 - 2 hours. It can be considered as safe lifting procedure with LI 1.0.

Condition 2: A safe lifting procedure with a light material, which has bad handles. 200 lifting are required with a duration range between 0 – 0.6 hour.

Condition 3: A frequent repetitive lifting job with a load of 18.1447 kg which has poor handles. The lifting duration range is between 3.0- 8.0 hours and desired lifting index is 2.0.

Condition 4: Considers a lifted load is 31.8042 kg with good handles. 300 lifting is required with a duration range is between 0- 8.0 hour. The LI is selected as 2.0 by the ergonomist.

Condition 5: This environment has the highest lifted load as 47.7064 kg with fair handles. 100 lifting are required and lifting duration range is between 0.3-3.3 hours. The ergonomist considers this environment as a risky job with LI 3.0.

Condition 6: This environment has the most frequent lifting with 2400. The lifted load is light and coupling quality constraint is fair. The time range is between 4.0- 8.0 hours. The LI is decided as 1.0.

4. COMPERATIVE ANALYSIS AND RESULTS

In order to compute sensitivity of proposed algorithm, 10 runs were produced for each of the six conditions. Harmony Search algorithm parameters were set as follows;

Number of iterations: 2500, Harmony Memory size: 200, HMCR: 0.70, PAR: 0.10.

As the best harmony was created, the algorithm also recorded the current iteration number, LI, and RWL for best harmony. After 10 run performed for each six work environment, 10 possible designs, the best of run design solutions for each harmony, were discussed and compared with Genetic Algorithm solutions. Table 5 summarizes the comparison of results by considering evaluated RWL and LI values. Harmony Search algorithm generated a bit better results than Genetic Algorithm especially for conditions with safe lifting tasks.

Table 5. RWL an LI of Genetic Algorithm versus Harmony Search

Condition	GA RWL	HS RWL	GA LI	HS LI
1	9.0966	9.0927	1.00	1.00
2	4.5494	4.5463	1.00	1.00
3	9.2721	9.0724	2.00	2.00
4	15.9021	15.9020	2.00	2.00
5	15.9021	15.9021	3.00	3.00
6	5.5637	5.4332	1.00	1.00

4.1 Performing 600 lifts at 9.0723 kg per lift (Condition 1)

The first workplace environment has a relatively light load lifted 600 times within a 2-hour time period. 10 Run Harmony Search algorithms find optimal design parameters for the first condition (Table 6).

There are many different suggestions for manual lifting design parameters by considering environmental limits. Although Harmony Search suggests high variable design parameters, algorithm could find desired lifting index value with an acceptable standard deviation and mean in different best combinations. If these results need more explanation, let us give an example;

#2, the loads can be grasped from 25.4 to 27 cm horizontally away from ankles with the starting height of the lift varying from 25.4 to 83 cm with up to 18° movement in horizontal plane. In order to meet safety and productivity requirements, the design would require that lifts be performed at a rate of approximately 5.7 lifts per minute for 105 minutes. All designs suggest nearly 5 or 6 lifts per minute for nearly 110 minutes. Under these conditions lifting index (LI) is 1.0 as desired, so #2 has proper design solutions and can be applicable in a real life. Carnahan and Redfern [11] also suggest different design solutions which satisfy desired lifting index and environmental conditions.

4.2 Performing 200 lifts at 4.5463 kg per lift (Condition 2)

The second workplace environment has a light load with only 200 total lifts and poor handle interface coupling required. Table 7 contains the best 10 solutions evolved under Condition 2, which are very different in design variables but consistent in LI and RWL. For example, in solution 5, the loads can be grasped between 25.4 and 36 cm horizontally away from the ankles at the start of the lift; however with a very low degree of asymmetry (2.4°). The design would require that lifts be performed at a rate of approximately 10.8 lifts per minute for 18.49 minutes as a maximum allowable time. As desired, these design parameters provide Recommended Weight Limit and Lifting index as 4.5463 kg and 1.0 respectively. Similarly, genetic algorithm provides desired RWL and LI in condition 2 [11].

Table 6. Near-optimal design of lifting task 1 - results of 10 run for the first environment

RUN	LI	RWL	Found Iteration	Harmony					#of Lifts/min
				H	A	Ve	Vs	D	
1	1	9,0929	1678	33	33	71	7,3	116	5,1
2	1	9,0927	1336	27	18	83	134	105	5,7
3	1	9,0921	632	28	11	156	14	120	5
4	1	9,0926	104	25	34	20	24	106	5,6
5	1	9,0925	534	29	48	35	6,1	118	5
6	1	9,0925	927	30	5,5	66	77	113	5,3
7	1	9,0926	369	29	18	55	83	117	5,1
8	1	9,0927	1828	32	25	102	9,8	120	5
9	1	9,0927	2139	27	10	59	4,4	93,7	6,4
10	1	9,0931	134	30	8	71	48	107	5,5

Table 7. Near-optimal design of lifting task 2 - results of 10 run for the first environment

RUN	LI	RWL	Found Iteration	Harmony					#of Lifts/min
				H	A	Ve	Vs	D	
1	1	4,5463	2140	42	56	108	12	21,1	9,4
2	1	4,5463	1210	42	125	18	3,3	29,8	6,7
3	1	4,5463	1355	35	126	143	69	31,5	6,3
4	1	4,5463	999	57	20	124	27	25,8	7,7
5	1	4,5463	2005	36	2,4	155	19	18,4	10,8
6	1	4,5463	1626	52	54	167	3,2	33,1	6
7	1	4,5463	1364	38	113	16	60	28,3	7
8	1	4,5463	1574	54	113	88	13	34,9	5,7
9	1	4,5463	1417	48	118	119	7,7	35,2	5,6
10	1	4,5463	869	41	114	59	5,7	24,4	8,1

Table 8. Near-optimal design of lifting task 3 - results of 10 run for the first environment

RUN	LI	RWL	Found Iteration	Harmony					#of Lifts/min
				H	A	Ve	Vs	D	
1	2	9,0724	35	28	25	97	59	436	2
2	2	9,0724	1486	32	34	83	1	431	2
3	2	9,0723	983	31	0	57	73	441	2
4	2	9,0724	2436	27	26	83	0,9	270	3,3
5	2	9,0724	199	27	46	96	72	470	1,9
6	2	9,0724	193	27	8,3	147	13	373	2,4
7	2	9,0721	1	27	40	69	53	354	2,5
8	2	9,0723	1309	26	56	126	13	460	1,9
9	2	9,0726	2401	32	27	103	0,3	468	1,9
10	2	9,0723	1049	32	16	66	44	459	1,9

Table 9. Near-optimal design of lifting task 4 - results of 10 run for the first environment

RUN	LI	RWL	Found Iteration	Harmony					#of Lifts/min
				H	A	Ve	Vs	D	
1	2	15,9048	2371	26	21	85	14	377	0,7
2	2	15,8963	2033	26	22	75	6,2	407	0,7
3	2	15,902	2353	27	20	69	2,9	460	0,6
4	2	15,9026	951	26	8,4	59	3,4	304	0,9
5	2	15,9044	2100	26	21	77	15	401	0,7
6	2	15,9015	1652	26	5,6	48	15	408	0,7
7	2	15,9023	621	27	20	82	13	109	2,7
8	2	15,9	1092	26	0,5	99	22	426	0,7
9	2	15,8969	277	27	3,4	78	13	356	0,8
10	2	15,9026	1355	28	3,7	82	2,4	384	0,7

Table 10. Near-optimal design of lifting task 5 - results of 10 run for the first environment

RUN	LI	RWL	Found Iteration	Harmony					#of Lifts/min
				H	A	Ve	Vs	D	
1	3	15,902	586	26	0,4	120	45	46,5	2,1
2	3	15,9023	1403	27	9,3	118	0,2	82,3	1,2
3	3	15,9027	2174	26	25	83	4,8	126	0,7
4	3	15,9019	2287	30	16	88	4,9	54,1	1,8
5	3	15,9012	2079	26	40	63	0,9	87,3	1,1
6	3	15,9021	1772	27	25	92	9,3	29,5	3,3
7	3	15,902	287	27	11	39	1,6	42,5	2,3
8	3	15,9024	1015	28	21	67	13	98,5	1
9	3	15,9022	1736	26	9,7	123	33	120	0,8
10	3	15,9024	1187	26	17	38	15	115	0,8

Table 11. Near-optimal design of lifting task 6 - results of 10 run for the first environment

RUN	LI	RWL	Found Iteration	Harmony					#of Lifts/min
				H	A	Ve	Vs	D	
1	1	5,4334	856	26	20	72	5	404	5,9
2	1	5,4333	516	26	6,9	156	25	448	5,3
3	1	5,4333	987	26	16	51	8,2	418	5,7
4	1	5,4336	463	27	50	56	22	465	5,1
5	1	5,4333	1591	28	52	96	20	468	5,1
6	1	5,4332	2198	28	34	85	36	450	5,3
7	1	5,433	1167	33	26	75	2,5	465	5,1
8	1	5,4332	297	28	42	95	41	479	5
9	1	5,4332	2223	29	6,2	94	76	454	5,2
10	1	5,4331	1654	30	0,6	61	5,5	432	5,5

4.3 Performing 900 lifts at 18.1447 kg per lifts (Condition 3)

The third environmental conditions have a high number of lifts with a moderate load 18.1447 kg and poor handle interface coupling quality. The best 10 solutions evolved under Condition 3 can be seen in Table 8. The designer from previous conditions as 2.0 differently chooses the LI. This means that this workplace environment is not as safe as first two conditions. Let us give an example design that is evaluated by Harmony Memory.

The first lifting design can be read as follows; the loads can be grasped between 25.4 and 28 cm horizontally away from the ankles at the start of the lift. The amount of asymmetry angle is set as 25°. The operator has to lift at an average rate of 2 lifts per minute for relatively high duration of 436 minutes. These design parameters provide Recommended Weight Limit and Lifting index as 9.0724 kg and 2.0 respectively.

4.4 Performing 300 lifts at 31.8042 kg per lift (Condition 4)

The fourth workplace environment consists of a heavier load with fewer repetitions. Table 9 presents the best 10 solutions under Condition 4. In solution #2, the loads can be grasped between 25.4 and 26 cm horizontally away from the ankles at the start of the lift. The amount of asymmetry angle is set as 21°. The allowable vertical height is 75 cm. Travel distance is set as 6.2 cm and in order to meet the production constraints, the solution requires the operator to lift at an average rate of 0.7 lifts per minute for relatively high duration of 407 minutes. Approximately, these design parameters provide RWL and LI as 15.8963 kg and 2.0 respectively.

4.5 Performing 100 lifts at 47.7064 kg per lift (Condition 5)

Condition 5 represents a heavy load with less repetition. Note that this condition is the risky lifting procedure in all six conditions, so that, LI is set to 3.0 by the ergonomist. The task is required to perform in less than 3.3 hours and required a heavy load (47.7064 kg). Table 10 contains 10 Run Harmony Search design solutions. The fourth solution suggests that the load can be grasped between 25.4 and 30 cm horizontally away from the ankles at the start of the lift. The amount of twisting permits the operator to turn 16°. The lifting duration is 54.1 minutes with a 1.8 lifts per minute. These design parameters provide RWL and LI as 15.9019 kg and 2.0 respectively.

4.6 Performing 2400 lifts at 5.4536 kg per lift (Condition 6)

Condition 6 is a repetitive lifting task with a light load. Design solution #4 in Table 11 can be explained as follows; the load can be grasped between 25.4 and 27 cm horizontally away from the ankles at the start of the lift. The amount of twisting permits the operator to turn 50°. The lifting duration is 465 minutes with a 5.1 lifts per minute. These design parameters provide RWL and LI as 5.4336 kg and 1.0 respectively.

These results show that proposed Harmony Search algorithm can easily be adopted to lifting design parameters and it gives sufficient design parameters similar to Genetic Algorithm.

5. CONCLUSIONS

Optimal designing a manual material lifting process carries weight with reducing stresses placed on the low back of human body. Lifting tasks must be carefully designed in order

to decrease high-priced Low-back injuries problems. Unfortunately, despite the fact that the lifting problems are critical and important in many industries, it has not achieved the prominence. In this study, NIOSH revised optimal lifting equations were used to find optimal lifting designs for this issue. The main complexity of the problem consists of the large number of unknown potential design combinations of lifting parameters. Six different industrial lifting problems were considered with different physical conditions according to the weight of lifting object, productivity plans, and workplace limitations such as travelling distance, repetition of the task, and duration. A strong meta-heuristic algorithm, Harmony Search, was modeled and presented to find near optimal work place design for given industrial limitations.

This paper aimed to get acceptable lifting designs, which provide ergonomic workplace conditions, by using Harmony Search algorithm and considering NIOSH revised lifting equation to minimize low back pain that occurs in lifting tasks. The developed algorithm provided multiple workplace designs as different harmonies with respect to work practices guide. Each harmony was evaluated to achieve optimal designs by using raw goodness and lifting index equations. Because the Harmony Search algorithm is an iterative heuristic approach, it gives many alternative designs, which are different from each other. Thus, Harmony Search algorithm can be used, as a proper method for the problem of workplace design requires lifting task in many industries. This study is the first attempt to develop and implement a Harmony Search algorithm for the workplace lifting design problem. The results of proposed algorithm were compared with genetic algorithm in the literature. It can be concluded that the proposed algorithm gave similar results with current approach.

6. REFERENCES

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