Virtual Reality Simulation of a Stacking Workstation

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ABSTRACT

This paper investigates and demonstrates the application of computer simulation for the determining the optimum design for laminations stacking workstation in a water pump assembly line in virtual reality environment. Ergonomic analysis, discrete-process simulation, and multi-response optimization approach were used concurrently to determine the optimum achievable design for a stacking workstation. In this context, "optimum" design entailed attainment of production quotas, avoidance of ergonomic deficiencies, economies of implementation and operational costs. The paper comprised attention to analysis of facilities, tooling system and ergonomic workplace design. More importantly, this can have a devastating impact on safety, quality, and cost.

The simulation model was constructed using five software applications. AutoCAD package was used for modeling the geometry of components. The four simulation tools were used to perform the ergonomic assessments for the number of alternative designs; also Design-Expert Software "DOE" for design of experiments to numerical optimization function finds maximum desirability of objectives simultaneously.

Keywords: discrete-process simulation, workstation, ergonomics, optimization.

1-INTRODUCTION

Computer simulation shows great promise for raising productivity, improving product quality, shortening lead times, and reducing costs in future. However, today the application of this technology is not very widespread in the manufacturing industry. One of the major reasons for this fact is that simulation modeling and analysis is labor intensive and time- consuming activity. Today the trend in manufacturing industry is to be more responsive to changes in product design and market conditions. Simulation modeling would tend to delay that process. Reducing time and the high level of effort will require the development of new simulation capabilities that automates the input of simulation parameters and data to speed up the model –building process [8].

The mainstream research in the application of simulation for solving manufacturing problems has focused on investigation of the dynamics of the current system and how it can be improved by additional equipment or better scheduling and a resources allocation system [5].

Similarly broad-based studies of production systems undertaken from a macro viewpoint are those of material flow and layout analysis in production of industrial vehicles [2], operations at a bulk-paper terminal [9], and collaborative improvement of layout and scheduling decisions considered collectively in a bulk manufacturing process [3]. First, this paper presents an overview of the production system. Next, we describe the development of the model (referring both to model design and to data collection), and the verification and validation of it. We then present results of the concurrent discrete-process and ergonomic simulation studies. Last, we summarize our discussion & conclusions.

2- OVERVIEW OF THE PRODUCTION SYSTEM

In State Company for Electrical Industries, the winding & insulating department is the one from the departments of the water pump assembly line. The department consists of five workstations included stacking, brazing, insulating, winding and testing as illustrated in figure (1). One operator for each workstation performed a job specified to them except the first one (stacking) where the manual material handling tasks for the laminations stator in that station achievable by two operators working in alternative period due to highly physical stress demand required for that job. According to the requirements of balancing on line, the capacity planning limited to 1000 stator for 8 hours shift work separated by 60 minute standard break period, laminations cylinder are continuous unloaded at the rate of 2.38 lifts per minute (i.e. 2.38 lifts / min. per tier are loaded). The time study for the processes in winding & insulating department confirmed that the long cycle time for first process (stacking) had significant effect in specified the capacity planning and total balancing for the line. This is the bottleneck station in the line. In order to increase the throughout of the line, redesign suggestions for station responsible about maximized cycle time should be execute. The basic configuration for this workstation comprised attention to facilities and tooling systems, material-handling systems, and ergonomic workplace. A checklists survey among 8 workers working at this station in different times, showed that among those who worked in an Existing stacking workstation design leads to long cycle time, uncomfortable work posture, bending, squatting, and forceful exertions when unloading stator laminations.

Depending upon the checklists indications, the existing workstation for stacking process presented in figures (1) needs changes in some components design and reconfiguration for layout of workplace.



Figure (1): Existing stacking workstation design

3 -MODEL DEFINITION AND DEVELOPMENT

3.1 Data Collection

The project scope, in turn, spawned understanding of which process data, such as *Ttask*, staking cycle time cycle times, *EShift*, the metabolic energy consumption, Ptask, the workers posture during the task, and **RWLtask**, the lifting limitations according to the NIOSH guideline would be required. Among these data, only the downtime data were stochastic. However, this simulation study, unlike those devoted solely to process simulation, additionally required detailed, accurate prints or CAD drawings to be integrated into the model. The Desirability Optimization Methodology (DOM) is being used as a useful approach to optimize workstation layout over a limited number of design variables. The proposed methodology (desirability function) as a decision making tool to select the best configuration from alternative solutions of workstation design, calculated in two steps, the first step concentrated on each criterion / response to assign an individual desirability. While the second step, applies Harrington's method [4] to estimate the system desirability, individual criteria desirability's were combined using optimization Response Surface Methodology (RSM)[6]

popularized by **Derringer and Suich** (1980) as techniques to find best solution.

3.2 Project Scope and Model Design

The vital part of any simulation study is setting clear project goals initially, especially since project scope, model design, and data collection efforts must be defined in the context of those goals. Here, the task of the study was the development of an improved workstation design under the following constraints: 1-Assume that the structure of the task is already given and aim to provide the most suitable physical environment for doing job, accordingly measures that are considered here are those that are affected by workstation design rather than work order. 2-Well-trained workers, percentage of 5th percentile males (weight 59.7 kg, 163.6 cm [1] with sufficient strength for four-task element as determined.

The main task is the manual handling of the laminations at the stacking workstation in Argon welding machine; we focus on ergonomics improvement and minimize the cycle time related to this task. All the factors are location (positioning) factors of stacking workstation. In particular these variables are: 1-Factor (A), the altitude measured in centimeters between the ground level and the base of the pallet which carrying the four tiers of laminations –four rows, nine columns in each tier.

2-Factor (B) is the horizontal distance in centimeters between mid point of ankles bones of the worker and the pallet.

3-Factor (C) is the vertical height in centimeters of the upper surface of the stacking machine and the head tip of the hydraulic cylinder.



Figure (2): The stacking workstation.

Choose deign factors influencing on the objective measures (ergonomics and economic measures). These factors are (A), (B), and (C) as illustrated in figure (2) and their values 80 cm, 35cm, and 40 cm respectively according to considerations for a well designed workstation can be found in [7]. The knowledge regarding which factors to include in the model is system-specific and considering as an art. It is usually based on experience. The verification and validation of the workstation model shown in figure (2) based on the following information available in table (1).

Daramatar	Fac	Dalta		
Falanietei	0	1	2	Dena
A (cm)	80	75	85	5
B (cm)	35	30	40	5
C (cm)	34	30	38	4

Table (1): Level of the investigated design factors.

3.3 Outline of the Methodology Steps

The suggested heuristic, which applies the methodology, consists of two parts. The first part is based on factorial experiments and handles discrete search over combinations of factor –level for improving the initial solution. In the second part, the solution that was obtained earlier is further refined by changing the continuous factor using (RSM). The flow chart of the suggested methodology is presented in figure (5) and describes in the following steps:

Step 1: Selecting design factors:

Choose design factors influencing the measures of interest (ergonomics and economic measures).

Step 2: Model those factors:

Model those factors by simulation of virtual reality design tools.

Step 3: Initialization:

Given feasible configuration of the investigated system (either from an existing system or by initial modeling and a set of performance measures, denote the initial configuration of n design factors by x_0 That is, x_0 is an n dimensional vector of factor levels (system setting)

Step 4: Modeling and feasibility test:

By using AutoCAD interface with Virtual Reality design tools (ErgoEaser, WinOWAS, EEPP, and MTM); can be used to evaluate different design configurations accurately for the model.

Step 5: Alternative solutions:

Generate a discrete space of M candidate design configuration. Use screening factorial design where the levels of each factor are selected as follows. Start with initial design and specify a range for each design factor that contains the current factor level. q Discrete points on such range define q possible level per factor and result in a q^n full factorial design. For limited experimental resources, a 2^n full -factorial design can be used by assuming a linear response model. Such design is obtained by considering only endpoints of factor ranges. Otherwise, the number of examined systems may be reduced by using Fractional Factorial Experiments (FFE). An ergonomic data report, which is generated by these analysis software(WinOWAS, EEPP, Ergo EASER and Method Time Measurement (MTM) analysis), is used to calculate the normalized performance measures. Accordingly, T_k , E_k , P_k and

 R_k denote respectively the *Ttask, Eshift, Ptask* and *RWLtask* performance measures values for solutions $k = 1, \dots, k$, . Since the desirability function require

performance measures values between zero and one, we apply the following normalization procedure according to equations (1) and (2) and desirability function given by equation (3) below. The experiments outputs are shown in table (2).

$$\begin{split} \tilde{\mathbf{T}}_{\mathbf{k}} &= (\mathbf{U'}_{\mathbf{T}} - \mathbf{T}_{\mathbf{k}}) / (1.2 \ (\mathbf{U}_{\mathbf{T}} - \mathbf{L}_{\mathbf{T}})), \quad \mathbf{k} = 1, \dots, k, \\ \tilde{\mathbf{E}}_{\mathbf{k}} &= (\mathbf{U'}_{\mathbf{E}} - \mathbf{E}_{\mathbf{k}}) / (1.2 \ (\mathbf{U}_{\mathbf{E}} - \mathbf{L}_{\mathbf{E}})), \quad \mathbf{k} = 1, \dots, k, \\ \tilde{\mathbf{P}}_{\mathbf{k}} &= (\mathbf{U'}_{\mathbf{P}} - \mathbf{P}_{\mathbf{k}}) / (1.2 \ (\mathbf{U}_{\mathbf{P}} - \mathbf{L}_{\mathbf{P}})), \quad \mathbf{k} = 1, \dots, k, \end{split}$$
(1)
$$\tilde{\mathbf{R}}_{\mathbf{k}} &= (\mathbf{R}_{\mathbf{k}} - \mathbf{L'}_{\mathbf{R}}) / (1.2 \ (\mathbf{U}_{\mathbf{R}} - \mathbf{L}_{\mathbf{R}})), \quad \mathbf{k} = 1, \dots, k, \end{split}$$

Where $U_T (L_T)$, $U_E (L_E)$, $U_P (L_P)$, and $U_R (L_R)$ are the upper (lower) limits of the four performance measures respectively and

$$\begin{aligned} U'_{T} &\setminus_{E} \setminus_{P} \setminus_{R} = U_{T} \setminus_{E} \setminus_{P} \setminus_{R} + 0.1 (U_{T} \setminus_{E} \setminus_{P} \setminus_{R} \\ -L_{T} \setminus_{E} \setminus_{P} \setminus_{R}), \quad \dots \dots \dots (2) \\ L'_{T} &\setminus_{E} \setminus_{P} \setminus_{R} = L_{T} \setminus_{E} \setminus_{P} \setminus_{R} - 0.1 (U_{T} \setminus_{E} \setminus_{P} \setminus_{R} \\ -L_{T} \setminus_{E} \setminus_{P} \setminus_{R}) \quad \dots \dots \dots \dots (2) \end{aligned}$$

The normalized values of, \tilde{T}_k , \tilde{E}_k , \tilde{P}_k and \tilde{R}_k represent the individual desirability grade for each one of the performance measures corresponds the one configuration for the manual workstation. Each performance measures are associated with a weight. The assigned weights imply that cycle time (*Ttask*) & (*Eshift*) is twice as important compared with other measures important (*Ptask*) and (*RWLtask*). In our case study v = 4, $d_{k,1} = \tilde{T}_k d_{k,2} = \tilde{E}_k$, $d_{k,3} = \tilde{P}_k$, $d_{k,4} = \tilde{R}_k$. Accordingly, the desirability functions as

in the following:

$$D\kappa = [\tilde{T}_{k}^{2} \times E \Box_{k}^{2} \times \tilde{P}_{k} \times \tilde{R}_{k}]^{1/6}, \ k = 1, \dots, k,$$

.....(3) Step 6: Feasibility test:

Check the feasibility of each solution, e.g., lack of collisions between environmental objects. Eliminate non-feasible solutions.

Step 7: Analysis:

Analyze the performance measures. Use multiobjective function (desirability), denoted by D (•), to evaluate the designs with respect to pre-defined performance measures and to select the best solution. Denote the best design solution known thus far by x^* . If all design factors are discrete (i.e. qualitative factors or ordinal discrete factors), go to step 10. If there exist continuous design factors, go to step 8.

Step 8: Applying optimization RSM techniques to refine the design solution:

Apply response surface techniques for model fitting. Check the validity of the model, for example, by using residual analysis. If required, fit a higher-order design such as Central Composite Design (CCD). Use the (**RSM**) to find optimal factor configurations on continuous scale that yields the expected best solution. Apply a multi-objective optimization technique. Denote the best solution obtained from the (**RSM**) by xR.

Step 9: Validation and feasibility test:

Simulate $x\mathbf{R}$ and evaluate its expected multiobjective performance, denoted by $D(x\mathbf{R})$. If $x\mathbf{R}$ feasible and $D(x\mathbf{R})$ is found to be superior than (x^*) , the expected multi-objective performance of the best design obtained thus far, set $x^* = x\mathbf{R}$.

Step 10: Termination condition 1:

If the improvement of the multi –objective performance is greater than δ , i.e., **D** (\mathbf{x}^*) - **D** (\mathbf{x}_0) > δ , or the maximal number of iterations, *J*, has been obtained, go to Step 12. Otherwise go to Step 11.

Step 11: New search for best design:

Set $x_0 = x^*$, thus defining the best configuration found thus far as a new initial solution. Increase the iteration counter by one, i.e., j = j + 1, and go to Step 5. *Step 12: Termination condition 2: Design workstations to accommodate people of different size:*

Evaluate the workstation design suitability adequately considering the broad range of people by make sure that the smallest worker (5th percentile value male) have the necessary muscle strength to perform this task, Otherwise go to Step 1.

Step 13: Termination:

Apply x^* to the investigated system. END

4- RESULTS OF THE STUDY

4.1 Early Results Pertaining to the Discrete Process Study

In the first phase of the study, industrial, process, the plant engineers and modeling team members compared 9 alternatives. Table (2) presents (8) configurations that are generated by editing the initial solution model. A validation of the ergonomic constraints performed on each model and it is found all alternatives are feasible. Simulation of each is done by WinOWAS, EEPP, Ergo EASER software's and Method Time Measurement An ergonomic report, which is (MTM) analysis. generated by these software's, is used to calculate the normalized performance measures. The desirability function of each alternative is evaluated. The performance measures are first normalized and the desirability function is then calculated using the relative importance values given in equation (3). The best solution is configuration (211) with desirability value 0.75. The initial solution is ranked in fifth place with a desirability value of 0.38. It is seen that not only (4) solutions superior to the initial solution, but also that the initial solution is dominated by three configurations (211, 212, 112). In other words, these configurations are superior to the initial solution in all objectives and, therefore, are considered better for any set of the reminder configuration solutions.

	Table (2). Simulation results of the alternative design solutions.										
Alternative	Exp. ABC	MT anal Tta (Se	ΓM lysis ask ec)	Ga anal Esl (kc	urg lysis hift cal)	OW anal Pta	/AS lysis lsk	NIOSH 91 analysis RWL task (kg)		Desirability	Feasibility test
		actual	norm.	actual	norm.	actual	norm.	actual	norm.		
0	000	9.267	0.38	807.3	0.42	1.250	0.26	5.57	0.45	0.38	ok
1	111	8.953	0.57	794.8	0.83	1.257	0.19	6.59	0.84	0.57	ok
2	112	9.164	0.44	792.7	0.89	1.248	0.28	6.39	0.76	0.56	ok
3	122	9.657	0.14	816.5	0.12	1.238	0.38	4.80	0.16	0.16	ok
4	222	9.336	0.34	813.7	0.21	1.215	0.62	4.80	0.16	0.28	ok
5	221	9.00	0.54	817.0	0.11	1.196	0.81	4.94	0.21	0.29	ok
6	211	8.508	0.83	800.3	0.65	1.205	0.72	6.59	0.84	0.75	ok
7	212	8.842	0.63	797.1	0.75	1.224	0.52	6.39	0.76	0.67	ok
8	121	9.447	0.27	813.7	0.21	1.218	0.59	4.94	0.21	0.27	ok
Upper limit		9.765		817.7		1.267		6.79			
Lower limit		8.400		792.0		1.186		4.60			

Table (2): Simulation results of the alternative design solutions.

4.2 Polynomial Response Fitting

Once the experiments are performed, model fitting techniques can be implemented to portray analytically the relations between input factors and the measures. Fitting is performed with respect to all performance measures. Table (4) is obtained from the Design Expert statistical software (DOE). This table contains modelfitting measures, including coefficients of determination and the contribution of each term to the model sum-of squares. The basis for such analysis is the use of higher order interaction effects (that are not included in the model) as an estimate for the experimental error. The required assumptions of uncorrelated error with mean zero and constant variance has to be carefully verified through residual analysis. A normal probability plot of the residual is presented in figure (3) and validate of none-linear response model, given in table (4). This non-linearity results from the significant interaction between factors A and B (base pallet altitude & horizontal distance between worker and the pallet).

Table (3) presents the list of factors with respect to all performance measures in decreasing order of importance. It is found that the base pallet altitude (factor A) affects three measures and that the horizontal distance between the worker and pallet (factor B) just affects the first measure *Ttask*. The hydraulic cylinder height (factor c) affects all the measures beside the *RWLtask*.

Table	(3):	Design	factors	in	decreasing	order	of
signific	ance y	with resn	ect to all i	nerf	ormance mea	sures.	

<i>Ttask</i> (MTM)	<i>Eshift</i> (Garg)	Ptask (OWAS)	RWL task (NIOSH)
A (+)	A(-)	A(+)	C(+)
B (-)	C(+)	C(-)	-

Factor	Sum-of-squares	D F	Mean square	F Value	F Value p-value Prob			
A	0.29	1	0.29	3.96		0.1849		
В	0.49	1	0.49	6.54		0.1249		
Full model	0.78	2	0.39	5.25		0.1600		
Residual	0.15	2	0.074	-		-		
Cor Total	0.94	7	-	-		-		
Model fitting measures	5							
Std. De	rv.	0.27	R-Squared		0.84	00		
Mean	!	9.11	Adj R-Squared		0.6800			
<i>C.V.</i> %			Pred R-Squared	-1.5600				
PRES	S	2.38	Adeq Precision	3.975				
Expected <i>Ttask</i> (MTM)= + 9.11- 0.19*A +	- 0.25*E	3					
Factor	Coefficient Estimate	DF	Standard Error	95% CI Low	95% CI High	VIF		
Intercept	9.11	1	0.096	8.70 9.53 -		-		
A-pallet base altitude	-0.19	1	0.096	-0.61	0.22	1.00		
B-horizontal distance	0.25	1	0.096	-0.17	0.66	1.00		





Student zed Residuals

Figure (3): A normal probability plot of the residuals of the response model for *Ttask*.

Figure (4), exemplifies such effect with respect to the *Ttask* (MTM) performance measure. From figure (4), the line clearly indicates that a highest value of factor (A) should be used where the base pallet closer to the worker and the cycle time (*Ttask*) will be decrease with increasing the value of this factor.

Since the design factors are continuous, one can refine the best solution found (configuration 211 in table (2) thus far by applying Response Surface Methodology (RSM) to find the best solution. Table (5) presents the initial conditions of both the performance measure and the design factors that are used by optimization procedure. The extrapolation presented in equation (1) used in this optimization step. Thus with respect to Ttask, Eshift and Ptask, the response gets a desirability grade of one if it is equal (or lower) to minimum value obtained in previous experiments minus10% of the observed range. As for the RWLtask measure, a desirability grade of one is obtained if the Recommended Weight Limit is equal (or higher) to the maximumvalue obtined in previous experiments plus 10% of the observed range. The lower and upper weights define the accumulation rate of the desirability grade. Weights of value one imply a linear accumulation rate. The importance column gives the relative importance of each performance measure with respect to others, as seen in equation (3). Table (5) also presents the search range for the design solutions. There are some extrapolation for the design factor values.



Figure (4): Affect of factor (A) (pallet base altitude) on *Ttask* performance measure with fixing the value of other factors (B&C).

That is, the three design factors that were extrapolation earlier with level values of one or two (in coded term) are now allowed to vary between 0.8 to 2.2. the reason for such extrapolation is the assumption that one can estimate the response functions over a wider search region by using responses obtained in a smaller experimental region [6]. Such assumption has to be checked at a later stage by validation experiment of the best design solution, particulrly if such a solution lies out of the experimental range.

 Table (5): Search region and definition parameters for the multiple desirability method.

Name	Goal	Lower limit	Upper limit	Lower weight	Upper weight	Importance
Factor (A)-pallet base altitude.	0.802.20	0.8	2.2	1	1	-
Factor (B)- horizontal distance.	0.802.20	0.8	2.2	1	1	-
Factor (c)- hydraulic cylinder height.	0.802.20	0.8	2.2	1	1	-

Ttask	≤ 8.400	8.400	9.765	1	1	2
Eshift	≤ 792.0	792.0	817.7	1	1	2
Ptask	≤1.196	1.196	1.257	1	1	1
RWLtask	≥ 6.79	4.00	6.79	1	1	1

Table (6) presents ten design solutions sorted in decreasing order by their desirability grades. For comparison purpose, two solutions from previous steps were added to the table: the initail solution given in step1(denoted in the table by IS), and the best "discrete" solution obtained at step 4 (denoted in the table by **DBS**). The best design solution that is obtained by the response optimization procedure (Design No. 1) achieves a desirability grade of 0.616. From table (6), the predicited value for the combined desirability obtained by RSM technique $(\mathbf{x}\mathbf{R})$ equal 0.616 smaller than to the actual value of the combined desirability for the best solution denoted by (x^*) and higher than for the initial solution (x_0) whose calculated in step 4 and its values 0.75 & 0.38 respectively. Surely many solutions can be found that have a desirability grade more than that in initial solution and same thing can be said actualy for the solutions have a less grade to the best solution.

The best solution obtained in step 6 is molded by the software's simulator (MTM, EEPP, WinOWAS and Eargo Easer) to validate its expected performance. Table (7) shows the performance measures for the best solution calculated by RSM technique in step 6 with design factors values are: A=86 cm, B= 29 cm, C= 30 cm.

The improvement of the multi-objective performance $D(x^*) > D(x0)$ and greater than δ ($\delta = 0.37$), i.e., $D(x^*) - D(x0) > \delta$. Since $D(x^*) = 0.7653 \& D(x0) = 0.38$, then $(D(x^*) - D(x0)) = 0.3853$. The improvement in objective function has achieved.

Number	Factor (A)	Factor (B)	Factor (C)	Ttask	Eshift	Ptask	RWLtask	Desirability
DBS	2	1	1	8.507	800.3	1.205	6.59	0.75
1	2.2	0.8	1	8.587	808.0	1.20085	5.77	0.616
2	2.2	0.8	0.992	8.587	808.0	1.20079	5.77	0.616
3	2.2	0.8	0.984	8.587	808.0	1.20073	5.77	0.616
4	2.2	0.8	0.970	8.587	808.0	1.20062	5.77	0.616
5	2.2	0.8	0.946	8.587	808.1	1.20044	5.77	0.616
6	2.2	0.8	0.944	8.587	808.1	1.20041	5.77	0.616
7	2.2	0.8	0.930	8.587	808.1	1.20031	5.77	0.616
8	2.2	0.8	0.924	8.587	808.1	1.20026	5.77	0.616
9	2.2	0.8	0.912	8.587	808.1	1.20018	5.77	0.616
10	2.2	0.8	0.900	8.587	808.1	1.20009	5.78	0.616
	:	÷	÷	÷	÷	:		:
IS	0	0	0	9.267	807.3	1.250	5.57	0.31

Table (6):	Design	solution	improvemen	t using	RSM.
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Table (7): performance measures of the best solutions selected in step 6 when molded by simulator software's.

Figure (5): Flowchart of the suggested methodology.

In this study there is no need for a new search for best design, only a single iteration was conducted. The final selected configuration was found to be superior to the initial configuration. Even that the workstation designed for a male of whose dimensions are at the 95th percentile value, the configuration design availability is to make sure a wide range of individuals can make use of the workstation. It is implies there is a male whom all her pertinent dimensions are at the 5th percentile value (height = 163.6 cm, weight = 59.7 kg) have a successful accommodation in various working postures with such workstation design. To test the availability of the workstation design, Three-Dimensional Static Strength Prediction Program (3D-SSPP) can perform a prediction of sufficient strength capability for a worker 5th percentile value with the best solution selected for the workstation design. The low back compression force is 564 N in safe mode and the strength percent capable is 25% for joints (elbow, shoulder, torso, hip, knee and ankle). According to this report, the vast majority of 5 percentile male workers have the necessary muscle strength to perform this task.

At this stage, the termination condition has to be checked. For illustration purposes, only a single iteration is allowed. Therefore, design Number 1 is selected as the best design, denoted by (x^*) , and the system is reconfigured accordingly.

5- DISCUSSION & CONCLUSIONS

The best design solution shown in table (7) represent the refining result for the best solution presented in table (2). It is based on different economic & ergonomics measures should be interpreted as follows:

Ttask: The cycle time per task is considerably affected by changes in factors' values. There is large difference of about 12.22 % between the best solution with **Ttask** = 8.477 seconds and the worst solution presented in table (2) (122 with **Ttask** = 9.657 seconds). In mass production environment, such as in this case this improvement is economically significant.

Eshift: The variation in energy consumption during the work shift among the different solutions is small (17.14 kcal) between the best solution with **Eshift** = 799.86 (kcal) and the solution involved higher oxygen consumption rate presented in table (2) (221 with **Eshift** = 817 kcal). The reason is that, energy-wise, the considered task is not a demanding one. A major portion of the energy consumption consists of the Basal Metabolism (the minimal amount of energy needed to keep the body functioning, when no activities are performed at all and the energy consumption for basic required body positions.

Ptask: The body position category is affected by configuration changes. The back position is found by the WinOWAS software to be the most relevant and problematic criterion. For example, during 25% of the time, the back position in the initial solution stands on category two, which may harm the worker in the long run. For comparison, in the best solution, the back position stands on category two in only 20.19 % of the task time.

RWLtask: The Recommended Weight Limit (RWL) in the initial solution is 5.57 kg. The best configuration has an average Recommended Weight Limit of 6.64 kg, thus an improvement of 19.21 %. Similarly to the **Ptask** analysis, it seen that the best solution obtained when factor (A) is fixed on its higher level.

The proposed methodology emphasized the advantages of combining computerized tools such as virtual reality, and statistical design approaches such as (RSM). Workstation is often characterized by continuous metric factors, such as height, length and depth that are well suited to be input factors to (**RSM**). In particular, the case study demonstrated that a dramatic improvement in workstation performances can be obtained by applying the proposed methodology to these factors. The best configuration obtained was superior to the initial configuration with respect toll performance measures and significant increase in a desirability measure, from 0.38 to 0.7653 was accomplished.

Appendix: - Trademark

-The ErgoEASER \bigcirc 1995 is held by U.S. Department of energy, Office of Environment, Safety and Health.

-WinOWAS is registrated trademark to Tampere university technology, occupational and safety engineering 1996, Finland.

-EEPP-Energy Expenditure Prediction Program[™] from the Center for Ergonomics at the University Of Michigan College Of Engineering, version 2.0, August 2005.

-Design-Expert software (DOE), Stat-Ease Inc, Version 7, 2006.

3D Static Strength Prediction Program, User's Manual, Ann Arbor, Michigan, 2005

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