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ERGONOMIC TECHNIQUES FOR ENHANCEMENT IN SPRAYING OPERATION AND REDUCING HUMAN INTERVENTION TO A MINIMUM BY MACHINE CONTROL OR CYBERNETICS

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Abstract - To safeguard the workers of industrial sprayers who involved in grimy, smeared activities and affected by MSDs (Musculoskeletal diseases) due to unsanitary condition and slovenly environment. Spray paint materials are toxic, flammable to the workers and surroundings.
The aim of the research was to establish a strategic model for ergonomics implementation for spray painting workers, basing on the theoretical background of ergonomics in order to improve the management of spray painting workers. This study has focused on finding a solution to the necessity of ergonomics approach in spray painting enterprises. The theoretical model and its implementation will enable organizations to apply the knowledge of ergonomics to production operations, in relation with interaction of technologies, work organization and human resources. A significant point made in this thesis is that the matter of ambiguous responsibilities can also be connected to organizational structure. This research will then focus on how the results of the ergonomic analysis can be used to drive the justification and design of potential automated solutions to improve the ergonomics of the task for the worker.

Key Words: OSHA, Musculoskeletal disorder, Heat Stress, EMIT Model.

1.INTRODUCTION

An industrial spraying operation, as defined by The Occupational Safety and Health Administration (OSHA), is “the employment of methods wherein organic or inorganic materials are utilized in dispersed form for deposit on surfaces to be coated, treated, or cleaned”

Musculoskeletal disorders (MSD) contains a wide variety of degenerative and inflammatory conditions which are causing pain and discomfort among the tendons, ligaments, muscles, joints, supporting blood vessels and nerves. Any mismatch between the requirements of the work, worker’s physical capacity and work environment leads to WMSDs. The etiology of WMSDs ranges from forceful or repetitive movements to poor working postures or environments and it affects worker’s body (Kuorinka, et al. 1987). Da Costa and Vieira (2010) studied that excessive repetition, awkward posture and poor working environment are the main risk factors of WMSDs.

Ergonomic studies may reveal that the risk to exposure to toxic chemicals is negligible, but the risk of heat stress is large
The product must meet not only functional and aesthetic requirements, but ergonomic quality requirements as well.
From the view point of design, evaluation of the psychological, morphological, physiological and biomechanical behavior of the users during the product use could significantly help in improving the product quality and its usability

2. METHODOLOGY

From the current literature on the human factors of industrial spraying tasks, it was evident that the ergonomic risks consisted of the two areas

General Risk Area	Details
Environmental	Exposure of chemicals in the air, heat, burns, etc.
Musculoskeletal	Musculoskeletal disorders (MSDs)in the back, hands, shoulders, wrists and otherupper extremities.

Table 1: General Risk areas for industrial spraying tasks, from the literature

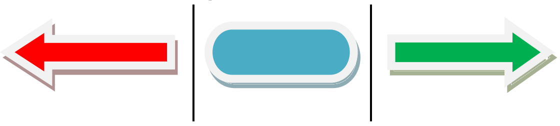
Using this research knowledge, it was determined that the ergonomic measures should specifically focus on the more detailed areas.

Risk Area	Details	Measure
Overall environmental risk	Examples include exposure to harmful chemicals and substances	OSHA recordable injuries and illnesses rate
Wrists and hands	Loads experienced by the wrists and hands, specifically from holding heavy equipment in unnatural postures	Job Strain Index (JSI)
Postures (Lower Back and upper extremities)	Industrial spraying operations typically force people to hold unnatural positions with	State Screening Tool
Heat risk	These tasks typically require workers to work in not air-conditioned environments in non-permeable protective clothing (ex- HAZMAT suit)	Heat Stress tool from the Health and Safety Executive

Table 2: Specific risk areas and their measures, for industrial spraying operations

The non-fatal occupational injuries and illness incidence rate is defined as "the number of employees per 100 full-time employees that have been involved in a recordable injury or illness". , this incident rate measures and covers the general environmental risks of industrial spraying tasks, such as slips, falls, injuries from equipment, and muscle strains.

THREAT ATTENTION SAFETY
R = 8 R = 4



Thresholds for OSHA incidence rates (R)

3. JOB STRAIN INDEX

The job strain index, developed by Cornell University's Ergonomics and Human Factors (Moore, J.S. and Garg, A. (1995) American Industrial Hygiene Journal 56:443-58) sector, measures the risk of injury to the hands and wrists based on the relevant factors of repetition, force, duration and posture of the hands and wrists

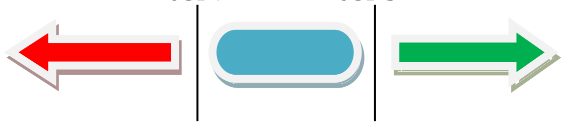
	Intensity of Exertion (IE)	Duration of Exertion (DE)	Efforts/ Minute (EM)	Hand/ Wrist Posture (HWP)	Speed of Work (SW)	Duration per Day (DD)
Exposure data	EFFORTFUL	72 %	15	BIASED	BIASED	6-10 hrs
Ratings	2.5	2.5	1.5	1	2	1.5

JSI = IE x DE x EM x HWP x SW x DD

JSI = 2.5 x 2.5 x 1.5 x 1 x 2 x 1.5 = 24.75

Table 3 :Job Strain Index Evaluation tool for the hands and wrists

THREAT ATTENTION SAFETY
JSI-7 JSI-3



Thresholds to use interpret results from the Job Strain Index

4. APPLICATION OF THE ERGONOMIC METHODOLOGY

This section aims to clarify and demonstrate the developed methodology.

4.1 The industrial spraying task studied

The industrial spraying operation analysis consist of cleaning several types of small manufacturing, military parts using two pressure washing methods:
(1) High temperature and
(2) High pressure power washing.

4.2 Ergonomic Measures and Data Collection

OSHA incidence rate calculation: The OSHA incidence rate proves to be a simple calculation, requiring the number of OSHA recordable injuries and illnesses and total number of worked hours (among all employees performing that job) over a period. Then, the formula standardizes the injury and illness data to span over 100 employees to allow companies to evaluate how safe a certain job is. The actual calculation is shown in the equation below.

$$\text{IR (Incidence Rate)} = \frac{\textit{Number of OSHA recordable injury or illness} \times 200000}{\textit{Number of Employee hours worked}}$$

Equation 1: OSHA recordable injuries and illnesses equation

There were 5 recordable injuries or illnesses recorded over a period of 1 year, in which 14 employees worked a total of 38,720 laborhours. These inputs were used to calculate the incidence rate for this task, and were used to analyze the overall safety of the work environment by comparing this number to industry standards.

4.3 Job strain index calculation

The Job Strain Index calculation method first requires the analyst to use the relevant tables toclassify each of the six measures of the tool (intensity of exertion, duration of exertion, etc.)

Figure , below, shows an example of the excel workbook and calculations for using this proxy method to determine the amount of time per shift that workers spent in the different, stressful postures.

Productive hours in a workday(hrs):	8	Legends	Attention	
			threat	
Area	**Description**	**% of time in this posture**	**Time per day in this posture(hrs)**	
Lower Back	Working with the back bent forward more than 30°(without support or the ability to vary posture)	20.10%	0.35	
	Working with the back bent forward more than 45°(without support or the ability to vary posture)	65.60%	4.19	
Hours spent in bent over posture per shift = % of time spent in posture *working hours per shift * weighting factor				
Hours spent in position per shift = 65.6% *8 hours * 80%=4.19				

Activity details	**Time with bent more then 45° without support (mins)**	**Total time observed in the random sample (mins)**
Inspecting and moving parts	2.6	5
Spraying	1.6	3
Getting supplies and spraying	3.93	4
Spraying and inspecting	3.67	6
	11.8	18
Total % of time spent with back bent more than 45°		65.60%

Table 4: Time analysis

4.4 Method for combining measures- EMIT model

Because these tools were combined as part of this research, to create a unique, intuitive methodology to evaluate industrial spraying operations, a methodology for combining the score swas derived. Due to the nature of the interactions between the different measures, a simple weighted factor model would not prove adequate for deriving an overall score for the overall ergonomics of the spraying task.

SEVERITY OF INJURY	**EXPOSURE**	**AVOIDANCE**	**RISK REDUCTION CATEGORY**
S2 Serious Injury more than first aid	E2 Frequent exposure	A2 Not likely	R1
		A1 Likely	R2A
	E1 Infrequent exposure	A2 Not likely	R2B
		A1 Likely	R2B
S1 Slight Injury first aid	E2 Frequent exposure	A2 Not likely	R2C
		A1 Likely	R3A
	E1 Infrequent exposure	A2 Not likely	R3B
		A1 Likely	R4

Table 5: Risk reduction classification matrix

In addition to providing a means of classifying the different levels of each category (severity, exposure, avoidance) as an overall score, this ANSI framework provides requirements for improving the safety of the robotic work cell. It requires all R1 and R2 risk levels to be improved, so that they become R3 or R4 risk levels (very low risk). Regarding the task of combining my four ergonomic tools for the industrial spraying operations ergonomic analysis, the ANSI model provides an excellent inspiration and framework.

Thus, inspired by the ANSI/RIA R15.06-1999 risk management framework, I developed a model, called the **EMIT (Ergonomic Measures Integration Tool) model**, to combine the results of the four ergonomic tools into a combined metric.

Legend 1	
T	Threat
A	Attention
S	Safety

Legend 2		Criteria
R1	Dangerous	2or more levels, or 4 attention levels
R2	Risky	1T level, or 3 attention levels
R3	Moderate risk	2 attention levels
R4	Safe	1 or fewer attention levels

Table 6: Definitions of terms and classification categories for the EMIT model

OSHA Rate	Job strain Index	State posture Tool	Heat stress checklist	Combination of scores	Risk level
T	T	T	T	TTTT	R1
			A	TTTA	R1
			S	TTTS	R1
		A	T	TTAT	R1
			A	TTAA	R1
			S	TTAS	R1
		S	T	TTST	R1
			A	TTSA	R1
			S	TTSS	R1
	A	T	T	TATT	R1
			A	TATA	R1
			S	TATS	R1
		A	T	TAAT	R1
			A	TAAA	R2
			S	TAAS	R2

Table 7: Part of the actual EMIT model to combine the ergonomic metric

5. RESULT

Current state ergonomic analysis Results

OSHA injuries and incidence rate

The resulting OSHA incidence rate for the industrial spraying operation analyzed was 25.8. This was derived from using the OSHA incidence rate formula with 1 year worth of data from the task studied. The interpretation of this number is that roughly 26 out of 100 employees would have a serious OSHA recordable injury or illness from this job in a span of one year.

The result of R = 25.8 puts this task well over the threshold for a Threat, and is off the scale

Figure 1: OSHA incidence rate metric current state results

5.1 Job Strain Index

The scoresfor each of the 6 parts of the job strain index tool are shown in the rating row, along with the description for each classification below it. The job strain index assessment resulted in a rangefrom 4.5 to 9, depending on whether the intensity of the task should be rated as somewhat hard or hard. For the purposes of this classification, the resulting overall classification will be the same whether this measure results in a threat (T) or attention(A) ranking.

The final classification of the job strain index for this case study evaluation is a A.

	Intensity of Exertion (IE)	Duration of Exertion (DE)	Efforts/ Minute (EM)	Hand/Wrist Posture (HWP)	Speed of Work (SW)	Duration per Day (DD)
Ratings	3	2	0.5	1.5	1	1
	6					
Description	Somewhat hard or hard	50-79%	<4	Fair	Slow	4-8 hrs

JSI = IE x DE x EM x HWP x SW x DD
JSI = 3.0x2.0x0.5x1.5x1.0x1.0
JSI = 4.5 or 9 (if IE is 6 instead of 3)

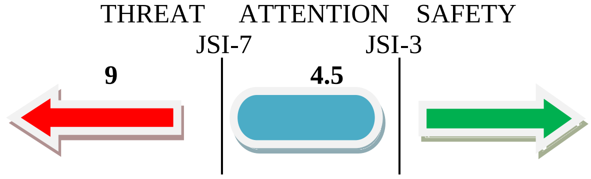


Table 9: Job Strain Index current state analysis results

5.2 State posture screening tool

The State posture screening tool assessment resulted in 4 categories (measures) being in the Threat zone, and the rest of the ten measures being in the no risk zone.

Area	Description	Risk	Actual Results (hours per day)
Lower Back	Working with the back bent forward more than 45°	Threat (>2 hours per day)	4.6
Hands and wrists grasp grip	Gripping Threat plus wrist deviation	Threat (>3 hours per day)	5.9
Hand arm vibration	Using grinders ,sanders,jigsaws or other hand tools that typicallly have moderate vibration levels	Threat(>4 hours per day)	5.9
neck posture	Working with the neck bent forward more than 45°	Threat(>4 hours per day)	4.6

Table 10: State posture screening tool current state results

5.3 Heat stress assessment tool

The heat stress assessment results indicated 3 measures above 1, and three measures below 1.

Area	Rating	Description of rating
Air temp	0	Neutral
Radiant temp	1	Heat source from sprayer is present and the tubing from the sprayer is hot to touch, Employees feel hot when they stand next to the heat source
Air velocity	-1	Cool air at a moderate air speed
Humidity	6	Vapour impermeable PPE is worn
Clothing	5	Light weight vapour barrier suits
Work Rate	2	Moderate hand and arm work, intermittently handling heavy objects

	SCORES											
	-3	-2	-1	0	1		2	3	4	5	6	Don't know
Air temperature				✓			✓					
Radiant heat					✓							
Air velocity			✓									
Humidity											✓	
Clothing										✓		
Metabolic rate							✓					

✓ **Case 1 : All times except the summer months**
✓ **Case 2: Summer months(the air temperature category shifts from 0nto 2;all other sources are same)**

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Table 11: Heat stress assessment tool results

5.4 Overall EMIT model results of the current state analysis

The total combination of results from the four ergonomic analysis tools is TATT.

The user can read off that an TATT combination results in an overall ergonomic analysis score of R1, the highest level of ergonomic risk. Thus, because the task resulted in an R1, steps should be taken to reduce the overall ergonomic risk to the worker. One main way to decrease these ergonomic risks is to automate or partially automate the spraying task. This will be explored in the following discussion/analysis section.

6. ANALYSIS

Areas of concern from the results of the classification tool

Based on the results from the full ergonomic analysis, the following areas proved to be the biggest causes for the unsafe ergonomics of the task (R1 ranking): (1) environmental safety, (2) wrist, (3) humidity, clothing, and metabolic rate (heat stress), (4) the lower back posture, (5) hands and wrists-grip, (6) hands and wrists-vibration, and (7) neck posture. These areas should be what is focused on when designing an alternative to improve the ergonomics of this industrial spraying task

Using the ergonomic analysis results to drive automation design decisions

Upon deciding to improve the ergonomics of this task with a partially automated solution, where robots clean the actual parts, engineers can use the results of the initial ergonomic analysis to drive some of the design decisions. For example, the environmental Threats were a Threat originally, so engineers should design the robotic work cell with extra attention to environmental Threats such as slippery surfaces, uneven surfaces, and ample warning signs, along with the robotic work cell safety features, such as an interlocking barrier around the robot. Secondly, to address the area of risk to the wrist, engineers should ensure that operators do not have to hold or manipulate controls or parts at awkward wrist angles

Regarding postures, engineers should pay special attention to all postures that were classified as Threats in the original ergonomic assessment, as well as new, relevant postures that may spring up with the new tasks of the workers

Potential solution: collaborative path planning, semi-automated work cell

One potential solution to greatly improve the ergonomics of this industrial spraying task is to partially automate is via collaborative path planning. Collaborative path planning is a way of using robotic algorithms to generate a path to follow after gathering a point cloud of data.

Workers' new job tasks

Now, because the robot arm now automatically generates a path to clean the parts and cleans the parts, the worker has a monitoring role, often called a supervisory role. Table 7 shows the worker's job duties before and after this collaborative path planning solution to improve worker ergonomics.

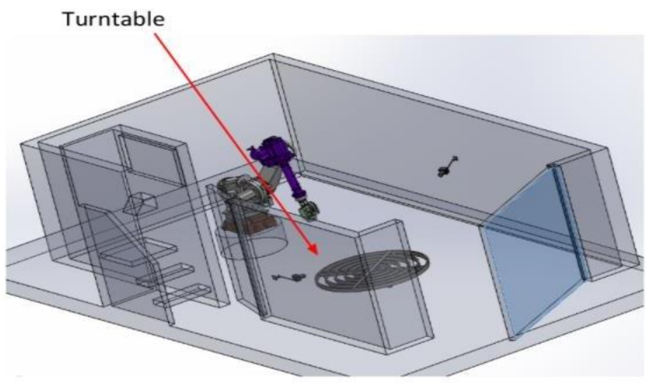

Figure 2: Potential Collaborative Path Planning solution work cell

	Before partial automation	After partial automation
Worker's job duties	(1) Moving parts, (2) Inspecting parts, (3) Gathering supplies, (4) Spraying parts	1.Supervising the robots, which are doing the spraying, 2. modifying the robot's path as needed, 3. addressing any errors made by the robot

Table 12: Worker's job duties before and after the collaborative path planning partialautomated solution

Evaluation of the new, semi-automated work-cell

Based on the workers' new job duties in this partially automated solution, the ergonomic analysis will be reassessed to see if the scores will improve, as desired. Note, that the reassessments are on the new, hypothetical role of the workers in this new, partially automated industrial spraying operation.

Out of the four measures will almost certainly be classified in the no risk category (N), instead of the Threat category (H). This is because if the worker does not have to hold the sprayer, bendover to spray parts, and move parts for most of their day, the posture and wrist risks will disappear.

Tool/ Measure	Before partial automation solution	**Ergo Improvements**
OSHA recordable injuries		Uncertain, but would likely improve the OSHA rate
Job strain Index		Duration would likely decrease to less than 10% ,intensity of exertion decrease to light (1)
State screening tool	After partial automation solution	All postures threats go away
Heat stress checklist		Humidity and clothing heat threat would go away

Tool /Measure	**Threats**	**Attention**	**Safety**
OSHA recordable injuries and illness incidence rate	**25.8** **R=8**	**R between 10 & 2**	**R=4**
Job strain index (JSI)	**4.5 -9** **JSI = 7**	**JSI=3**	**JSI between 0.25 & 2**
State screening tool (posture)	**4 or more Ts**	**1 or more T**	**No Threats**
Heat stress checklist	**3 or 4 measure** **3 measure > 1**	**2measure > 1**	**No measures >1**

Figure 3: Overall results of the ergonomic analysis before and after the partially automated solution

Justification for automation

Overall, the resulting score of R4 from the ergonomic evaluation of the partially automated solution shows that the ergonomics for workers drastically improved from implementing this solution with automation. Thus, this provides a justification for automation from an ergonomics perspective. Although other factors will likely still be considered when automating, such as the financial return on investment and productivity, thisergonomic measure is also important in justifying automation. Although improvements in safety can, to some degree, be quantified in dollars, protecting employees should be a toppriority for companies.

7. CONCLUSION

This research accomplished the initial goals of the analysis, namely creating a tool to comprehensively evaluate the ergonomics of industrial spraying tasks, using the tool to assess a task before and after implementing a potential partial automated solution, and using these resultsto justify a solution involving automation. The overall conclusions from this research are as follows:

1. Industrial spraying tasks can be comprehensively evaluated, and the tool developed from this research can be used by people without ergonomics backgrounds to evaluate the ergonomics of any industrial spraying task.
2. The ergonomic methodology derived from this research can be used to effectively improve the ergonomics of an industrial spraying task by helping to justify automated (or partially automated) solutions and make design decisions regarding new environments and work tasks for workers.

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