Hierarchical Controls Assessment for Ergonomics Risks in Maintenance Operation An applied research

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Résumé:

Today, Sri Lanka stands strong as one of the premier fashion and apparel outsourcing hubs in the world, possessing a wealth of long established culture, which represents ethical entrepreneurship and sustainability. At present, the country is on a seamless and relentless process of setting up a unique platform to accomplish its ascendancy through superior quality, incomparable turnaround time and adoption of state-of-the-art technology. www.ft.lk (2015). Plant maintenance plays a major role on efficiency of manufacturing process and to have apparel sectors' recognition over safe plant operations, maintenance functions have to be well complying with safety standards. Maintenance operation involves unique Human Factor challenges due to both Physical demands under restricted access and Psychological demands such as problem solving. Due to these challenges, maintenance operation is recognized as carrying risks on the system as well as on the human. Risk evaluation with hierarchy of controls is a methodology utilized in industry in the management of hazards and risks to eliminate or reduce employee exposures. Elimination, Substitution, Engineering Controls, Administrative Controls and Personal Protective Equipment (PPE) is the common hierarchy used when identifying solutions to minimize employee exposure to the hazards. BS 8800 (2004). This applied research is based on an Industrial Project where Risk Evaluation was conducted with focus in determining the ways of preventing from Ergonomic Risks in maintenance operation. Hierarchy of controls being the basis, this research presents the evaluation done over the maintenance operation, risk preventions methods and suggests a Study Model that might be used generally in industry to determine Ergonomic Risk Prevention of Maintenance work.

1. Introduction

Globalization of the economy has intensified over the recent years and, together with the development of the new information and telecommunications technology, it is bringing about radical changes in society, comparable to those produced during the industrial revolution. Occupational safety and health cannot ignore those changes. And, in this context, the greatest challenge for the countries is the transformation of the difficulties involved in adapting to the new situation into opportunities for the future development of OSH. López-Valcárcel (2002). Transfer of technology and industrial development without consideration for the characteristics of the local users and the environmental conditions of the recipient countries has proved to be not only socially destructive but economically expensive in terms of human suffering and material losses. Most developing countries are paying an unacceptably high price in terms of suffering, sickness and also loss of production due to work-related accidents. Poor working conditions and non-existence of an effective injury prevention program in many developing countries has resulted in a very high sickness and accident rate. Shahnavaza, H (2010)

1.1. Maintenance and influence on safety

Historically, management has devoted much of its effort in improving manufacturing productivity by probing, measuring, reporting and analyzing manufacturing costs. Similar efforts in regard to maintenance function productivity are long overdue. It is observed that there has been a general lack of synergy between maintenance management and quality improvement strategies in the organizations, together with an overall neglect of maintenance as a competitive strategy. Wireman, T. (1990)

Safe performance of maintenance tasks is an essential responsibility of all manufacturing facilities. Workers may be exposed to hazardous energy in several forms during installation, maintenance, service or repair work. Apart from the physical hazards, there exist psychological and environmental hazards respective to maintenance operations due to unique demands of problem solving and exposure to special environments those are not usual in regular operations.

Plant and equipment maintenance and repair tasks have long posed challenges ranging from human performance issues leading to acute traumatic injuries and fatalities (Cawley, 2003; Lind and Nenonen, 2008), reduced equipment availability during troubleshooting and repair, and equipment failure due to errors during maintenance. Not only is this work non-routine, there are, among other issues, machine and electrical hazards, materials handling exposures, falls, access issues that restrict posture and increase biomechanical demands, and injuries associated with hand tools. In published research, these problems have been approached from several viewpoints including engineering (Harring and Greenman, 1965; Unger and Conway, 1994), human error and ergonomics (Dhillon and Liu, 2006; Koli et al., 1998; Mason, 1990), and risk assessment (Lind et al., 2008). In a study of fatal or severe injuries sustained during plant maintenance, Lind (2008) found that 48 percent of 33 fatalities studied occurred during planned preventive operations. For fatalities, the leading causes were being crushed or caught between (27 %) and falls (27 %). For severe non-fatal injuries, the leading causes were being crushed or caught between (39 %) and jumping or falling (21 %).

In addition to falls and traumatic injuries from incursions with machinery or parts, maintenance tasks in aviation maintenance were found to pose ergonomics deficiencies including frequent awkward and restricted postures, working in hot and noisy environments, forceful exertions, and manual materials handling (Chervak and Drury, 1996). To address these latter exposures, Koli et al. (1998) developed an ergonomics audit as an approach to assess human-system mismatches in aviation maintenance.

1.2. Ergonomics considerations in Maintenance

As defined by International Ergonomics Association (IEA) in their official web site http://www.iea.cc Ergonomics (or human factors) is the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimize human wellbeing and overall system performance. Maintenance task in general is different from the routine machine operation task because it requires special problem solving skills, reach to unfavourable locations such as high places and narrow spaces, working in awkward postures, insufficient space for the hand movements or seeing, lack of free space, excessive force required for irregular operations, poor lighting and thermal conditions and high noise and vibration levels hazards. From an ergonomics standpoint, addressing issues associated with maintenance and repair activities is difficult due to the variable nature of the work, the changing location of the tasks, and the inherent complexity of accessing, diagnosing, and repairing various types of equipment. These complexities may partly explain why there has been comparatively little ergonomics research addressing maintenance.

1.3. Risk assessment

Hazard identification and risk assessment involves a critical sequence of information gathering and the application of a decision-making process. These assist in discovering what could possibly cause a major accident (hazard identification), how likely it is that a major accident would occur and the potential consequences (risk assessment) and what options there are for preventing and mitigating a major accident (control measures). These activities should also assist in improving operations and productivity and reduce the occurrence of incidents and near misses. There are many different techniques for carrying out hazard identification and risk assessment. The techniques vary in complexity and should match the circumstances. Collaboration between management and staff is fundamental to achieving effective and efficient hazard identification and risk assessment processes. http://www.comcare.gov.au (2013)

Failure mode and effects analysis (FMEA) was one of the first systematic techniques for failure analysis. It was developed by reliability engineers in the late 1950s to study problems that might arise from malfunctions of military systems. A successful FMEA activity helps to identify potential failure modes based on experience with similar products and processes or based on common physics of failure logic. It is widely used in development and manufacturing industries in various phases of the product life cycle. Effects analysis refers to studying the consequences of those failures on different system levels.

It involves reviewing as many components, assemblies, and subsystems as possible to identify failure modes, and their causes and effects. For each component, the failure modes and their resulting effects on the rest of the system are recorded in a specific FMEA worksheet. A FMEA is mainly a qualitative analysis. Rausand (2004). FMEA is an inductive reasoning (forward logic) single point of failure analysis and is a core task in reliability engineering, safety engineering and quality engineering. The failure probability can only be estimated or reduced by understanding the failure mechanism. Ideally, this probability shall be lowered to impossible to occur by eliminating the root causes. It is therefore important to include in the FMEA an appropriate depth of information on the causes of failure.

FMEA analysis comprises of three major ratings Severity, Occurrence and Detection. Severity is determined by the Severity for the worst-case scenario adverse end effect. The likelihood of occurrence can be estimated by analysis, looking at similar items or processes and the failure modes that have been documented for them in the past. The means or method by which a failure is detected, isolated by operator and/or maintainer and the time it may take defines the Detection rating. It should be made clear how the failure mode or cause can be discovered by an operator under normal system operation or if it can be discovered by the maintenance crew by some diagnostic action or automatic built in system test.

1.4. Hierarchy of Controls

The most important step in managing risks involves eliminating them so far as is reasonably practicable, or if that is not possible, minimizing the risks so far as is reasonably practicable. There are many ways to control risks. Some control measures are more effective than others. Various control options must be considered and the control that most effectively eliminates the hazard or minimizes the risk in the circumstances must be chosen.

In an occupational health and safety context, risk control is often categorized according to an effectiveness hierarchy often simply called the risk control hierarchy. The hierarchy lists the type of control measures in a priority order; based on the extent each measure has an impact on risk. Hierarchies of prevention and control measures have been developed by different institutions. A risk assessment has identified hazards that require control, there are some considerations which, can be addressed before going on to setting priorities for controlling them. As listed in BS8800, the most effective control measure involves eliminating the hazard and associated risk. The best way to do this is by, firstly, not introducing the hazard into the workplace. Eliminating hazards is often cheaper and more practical to achieve at the design or planning stage of a product, process or place used for work. In these early phases, there is greater scope to design out hazards or incorporate risk control measures that are compatible with the original design and functional requirements. If it is not reasonably practical to eliminate the hazards and associated risks, then the risk should be minimised by using one or more of the following approaches. Boyle, T (2008)

- Substitute: If the hazard cannot be eliminated, substitute or replace the hazard with a less hazardous work practice.
- Engineering controls: Physical control measures such as adapt tools or equipment to minimise the risk.
- Administrative controls: Work methods or procedures that are

designed to minimise the exposure to a hazard

- Personal Protective Equipment (PPE):PPE relies on the proper fit and use of the PPE and does nothing to change the hazard itself. It therefore requires thorough training and effective supervision to ensure compliance and effectiveness.
- Minimising effort may involve a single control measure or a combination of different controls that together provide the highest level of protection that is reasonably practicable.

2. Problem Description

Along the hierarchy, ways of controlling risks are ranked from the highest level of protection and reliability to the lowest. www.safework.sa.gov.au (2011). Health and Safety regulations require to work through this hierarchy when managing risks. First attempt should be to eliminate a hazard, which is identified as the most effective control. If elimination is not reasonably practicable, risk must be minimized by working through the other alternatives in the hierarchy. The problem studied in this research is when controlling different types of Ergonomic risks particularly in maintenance operation with reasonably practical and effective controls, whether those controls flows in the general hierarchy those are used in Industry to address safety hazards in common.

3. Objectives

Overall goal being studding the fit of controls along the hierarchy for ergonomic risks in manufacturing sector, below objectives are planned in this research.

- To Identify Ergonomics Risk factors in selected maintenance operations and categorize them as physical, psychological and environmental
- To determine list of Hierarchical controls to prevent ergonomic risk factors
- To Study the relationship between improvement of Human Factors along the Hierarchy of controls
- To suggest a model based on the Hierarchical Controls that can be used to evaluate and determine controls to prevent ergonomic risk factors in the maintenance operation.

4. Methodology

This research is a form of systematic inquiry, researcher involving the practical Ergonomics applications to control risks during maintenance operations. The framework utilized for implementation of risk controls was studied in an apparel accessories manufacturing organization in Colombo, Sri Lanka of which the head office is located in California, USA. Organization rolled out a structured project to identify and mitigate risks in maintenance operations. The maintenance operations were carried out in manufacturing facilities of 5 different product lines; Offset printing, Flexography printing, Screen printing, Thermal printing and Weaving technologies. Researcher was a team member of the Ergonomics risk assessment program.

Maintenance operations were analysed for Physical, Psychological and Environmental risk factors using a Work Place Analysis checklist developed by the author particularly for assessment of maintenance operations. Each of the maintenance activity was evaluated for below multiple ergonomic aspects.

- Physical Job Restrictiveness
- Physiological Work Postures and movements
- Psychological Stress
- Cognitive (Job Content, Difficulty in decision making, Repetitiveness of the work, Attentiveness, Worker Communication)
- Environmental (Noise, Heat, Light and vibration)

By a group of experts including the maintenance staff and operators, risks were then rated using the Failure Mode and Effect Analysis (FMEA) considering Severity, Occurrence and Detection. Each risk factor was assessed for control method in the sequence of elimination, substitution, engineering controls, administrative controls and PPE. Each control method identified was also evaluated using an implmentability score. Impacts of suggested controls were again rated using FMEA. Correlation of the Impact Rate was calculated against the order in the control Hierarchy. Exercise covered all three ergonomic risk factors physical, psychological and environmental.

5. Results and Discussion

This chapter is organized to discuss the ergonomic risks identified, their categorization in to physical, psychological and environmental. Further, assessed risks using FMEA, identified controls, nature of control and assessed impacts are explained.

5.1. Identification of Ergonomic Risk Factors

There were 30 maintenance tasks studied using the ergonomic checklist leading to 25 ergonomic risk factors. Those comprised of 11 physical risk factors, 9 psychological risk factors and 5 environmental risk factors. Listed below is the list of ergonomics risks identified.

5.1.1. Environmental Risk Factors

- Cannot make observations due to discomfort glare
- Deposit not detected due to poor contrast between original color and deposits
- Exposure to high temperature due to limited air movements inside
- High noise emission during machining
- Illumination level not adequate for visual demands required

5.1.2. Physical Risk Factors

- Controls are not in comfortable visual range
- Dangerous to touch due to high temperature
- Dangerous to touch vibration
- Difficult enclosure or panel removal
- Labels are not big enough to see in comfortable posture
- No adequate access for manipulative & precise tasks
- Physical effort requiring due to no quick disconnects available
- Task requires accurate position movements
- Task requires exact application of muscular force
- Task requires prolong static muscular force
- Whole body clearance is not sufficient

5.1.3. Psychological

- Controls and tools are not positioned correctly in order leading to control error
- Controls and tools cannot be recognized by touch
- Design provides many means of reassembly leading to confusion
- Incremental change presented with digital display leading to attention lost
- Instantaneous values presented with analogue leading to attention lost
- Machine-related auditory signals not distinguishable from each other
- Repetition of test to verify readiness leading to boredom
- System accepts incorrect components
- Warning lights are not of meaningful colors and flashing

5.2. Risk assessment of Ergonomic Risk Factors

As the first steps to take when completing an FMEA it is required to determine the participants to conduct the assessment. Representatives from the machine operations, maintenance staff, safety staff and quality assurance staff those are having more than 5 years of experience were involved to review the list of risk factors and to estimate 3 criteria of the potential failure. FMEA uses below three criteria to assess a failure,

a) Severity of the effect on the user
b) How frequently the problem is likely to occur
c) How easily the problem can be detected.

Participants agreed on a ranking between 1 and 10 (1 = low, 10 = high) for the severity, occurrence and detection level for each of the failure modes. Although FMEA is a qualitative process, it is important to use available data to qualify the decisions the team makes regarding the ratings. Thus, historical incident records were made use of estimating the Occurrence of the failure. A further explanation of the ratings is shown in Table 1.

	Description	Low Number	High Number
Severity	Severity ranking encompasses what is important to the industry, company or customers (e.g., safety standards, environment, legal, production continuity, scrap, loss of business, damaged reputation)	Low impact	High impact
Occurrence	Rank the probability of a failure occurring during the expected lifetime of the product or service	Not likely to occur	Inevitable
Detection	Rank the probability of the problem being detected and acted upon before it has happened	Very likely to be detected	Not likely to be detected

Table 1: Severity, Occurrence and Detection Ratings

After ranking the severity, occurrence and detection for each failure mode, then risk priority number (RPN) of each risk were calculated. Table 2 present the list of risk factors and results of risk assessment

The formula for the RPN is:RPN = Severity x Occurrence x Detection

	Severity	Occurrence	Detection	RPN
Environmental				
Exposure to high temperature due to limited air movements inside	6	7	4	168
Illumination level not adequate for visual demands required	6	6	4	144
Deposit not detected due to poor contrast between original colour and deposits	3	4	8	96
High noise emission during machining	6	5	2	60
Cannot make observations due to discomfort glare	5	4	3	60
Physical				
Difficult enclosure or panel removal	6	6	7	252
Task requires prolong static muscular force	7	4	8	224
Dangerous to touch due to high temperature	7	3	8	168
Controls are not in comfortable visual range	5	5	6	150
Task requires exact application of muscular force	7	7	3	147
No adequate access for manipulative & precise tasks	4	6	6	144
Labels are not big enough to see in comfortable posture	4	4	7	112
Dangerous to touch vibration	4	3	8	96
Physical effort requiring due to no quick disconnects available	4	5	4	80
Task requires accurate position movements	5	3	4	60
Whole body clearance is not sufficient	7	3	2	42
Psychological				
Design provides many means of reassembly leading to confusion	6	3	7	126
Machine-related auditory signals not distinguishable from each other	3	4	7	84
System accepts incorrect components	4	4	4	64
Controls and tools are not positioned correctly in order leading to control error	3	4	4	48
Warning lights are not of meaningful colours and flashing	3	4	4	48
Incremental change presented with digital display leading to attention lost	3	4	4	48
Instantaneous values presented with analogue leading to attention lost	3	4	4	48
Repetition of test to verify readiness leading to boredom	2	4	5	40
Controls and tools cannot be recognized by touch	3	2	4	24

Table 2: Risk factors and results of risk assessment

5.3. Determination of control measures and their impact

Boyle (2008) discusses the question of how to select the best option of prevention and control measures and presents some criteria In general, it is better to use a risk control measure which will protect everyone who could be exposed to the hazard, rather than relying on individuals to provide their own protection. The extent to which the continuing effectiveness of the risk controls measure relies on human behaviour. In general, it is preferable to have risk control measures which, apart from any necessary maintenance, operate without human intervention. When a risk control measure relies on the actions of people, it is inevitable that on some occasions it will not be used, either deliberately or inadvertently. The extent to which the risk controls measure requires testing, maintenance, cleaning, and replacement and so on. All of these required activities rely on human intervention and can, therefore, fail. This reduces the likelihood that the risk control measure will continue to be effective.

Each risk factor identified was evaluated for suitable control. All 25 risk factors were assessed for alternative five controls along the hierarchy.

Estimated improvement in Severity, Occurrence and Detection were again assessed in all the alternative controls identified. Ideally, the cost should be calculated over the whole of the time for which risk control is required, since some risk control measures have a low installation cost but are expensive to maintain, while others have higher installation costs but are cheaper to maintain. And the extent to which the risk controls measure reduces the risk. Ideally, a risk control measure, or combination of measures, will reduce the risk to near zero, but this may not be achievable in practice.

Out of the control measures identified, those were having own challenges in the implementation. Implementability related to number of factors, some of which are intrinsic and therefore are under the control of the plant officials and some of which are extrinsic. A score of 1-5 was assigned to each control based on the easiness of implementation.

Impact ratio was multiplied by implementability, in-order to get a single score of the applicable impact of the controls identified. Some of the risk factors did not have an applicable control under some hierarchy positions; the implementability was rated as 1 to make no difference under that control. Impact ratio was calculated by dividing the original RPN by the improved RPN (RPNi). Impact of Severity, Occurrence and Detection were calculated separately by dividing each of them by the improved numbers. Table 3 presents the details of arriving to Impact Ratio X Implementability for 6 risk factor (2 from each risk type) and control under each hierarchy as an example of the exercise.

Some of the controls resulted in imposing different ergonomic impacts under same ergonomic risk nature those were tried to resolve or led to issues of some other ergonomic nature. Table 4 presents such interdependencies noted.

Ergonomic Risk Factor	Risk Nature	S	O	D	RPN	Hierarchy Control	Hierarchy Possition	Description of the Control	Si	Oi	D'	RPNi	Impact Ratio	Implement ability	Impact Ratio X Implementability	IR s	IR o	IR d
Exposure to high temperature due to limited air movements inside	Environmental	6	7	4	168	Eliminate	1	Avoid repair features inside	6	2	4	48	3.5	1	3.5	1.0	3.5	1.0
		6	7	4	168	Substitute	2	N/A	6	7	4	168	1.0	1	1.0	1.0	1.0	1.0
		6	7	4	168	Engineering	3	Introduce forced air movements	3	7	4	84	2.0	5	10.0	2.0	1.0	1.0
		6	7	4	168	Admin	4	Introduce frequent rest pauses	6	3	4	72	2.3	3	7.0	1.0	2.3	1.0
		6	7	4	168	PPE	5	Provide least PPE to limit thermal discomfort	5	7	4	140	1.2	2	2.4	1.2	1.0	1.0
Cannot make observations due to discomfort glare	Environmental	5	4	3	60	Eliminate	1	N/A	5	4	3	60	1.0	1	1.0	1.0	1.0	1.0
		5	4	3	60	Substitute	2	N/A	5	4	3	60	1.0	1	1.0	1.0	1.0	1.0
		5	4	3	60	Engineering	3	Provide cover on the glare source	2	4	3	24	2.5	4	10.0	2.5	1.0	1.0
		5	4	3	60	Admin	4	N/A	5	4	3	60	1.0	1	1.0	1.0	1.0	1.0
		5	4	3	60	PPE	5	Provide Safety goggles	3	4	3	36	1.7	5	8.3	1.7	1.0	1.0
Difficult enclosure or panel removal	Physical	6	6	7	252	Eliminate	1	N/A	6	6	7	252	1.0	1	1.0	1.0	1.0	1.0
		6	6	7	252	Substitute	2	Redesign panel fasteners	3	6	7	126	2.0	3	6.0	2.0	1.0	1.0
		6	6	7	252	Engineering	3	Provide suitable hand tools	4	6	7	168	1.5	3	4.5	1.5	1.0	1.0
		6	6	7	252	Admin	4	N/A	6	6	7	252	1.0	1	1.0	1.0	1.0	1.0
		6	6	7	252	PPE	5	N/A	6	6	7	252	1.0	1	1.0	1.0	1.0	1.0
Physical effort requiring due to no quick disconnects available	Physical	4	5	4	80	Eliminate	1	N/A	4	5	4	80	1.0	1	1.0	1.0	1.0	1.0
		4	5	4	80	Substitute	2	Introduce quick disconnects	1	5	4	20	4.0	3	12.0	4.0	1.0	1.0
		4	5	4	80	Engineering	3	Introduce hand tools for disconnecting	2	5	4	40	2.0	2	4.0	2.0	1.0	1.0
		4	5	4	80	Admin	4	N/A	4	5	4	80	1.0	1	1.0	1.0	1.0	1.0
		4	5	4	80	PPE	5	N/A	4	5	4	80	1.0	1	1.0	1.0	1.0	1.0
Design provides many means of reassembly leading to confusion	Psychological	6	3	7	126	Eliminate	1	Eliminate handling of multiple components	6	1	7	42	3.0	1	3.0	1.0	3.0	1.0
		6	3	7	126	Substitute	2	Introduce different shapes to connects	4	3	7	84	1.5	3	4.5	1.5	1.0	1.0
		6	3	7	126	Engineering	3	Follow Standard measurements	6	3	3	54	2.3	2	4.7	1.0	1.0	2.3
		6	3	7	126	Admin	4	Provide instruction sheet with schematic diagrams	6	3	4	72	1.8	2	3.5	1.0	1.0	1.8
		6	3	7	126	PPE	5	N/A	6	3	7	126	1.0	1	1.0	1.0	1.0	1.0
Incremental change presented with digital display leading to attention lost	Psychological	3	4	4	48	Eliminate	1	N/A	3	4	4	48	1.0	1	1.0	1.0	1.0	1.0
		3	4	4	48	Substitute	2	Change to analogue display	3	4	2	24	2.0	1	2.0	1.0	1.0	2.0
		3	4	4	48	Engineering	3	Introduce warning alarm	3	4	3	36	1.3	1	1.3	1.0	1.0	1.3
		3	4	4	48	Admin	4	Display limits as instructions	3	4	3	36	1.3	1	1.3	1.0	1.0	1.3
		3	4	4	48	PPE	5	N/A	3	4	4	48	1.0	1	1.0	1.0	1.0	1.0

Tabel 3: Calculation of Impact Ratio

Ergonomic Risk Factor	Risk Nature	HC	Description of the Control	Resulting effects on other HF	HF effected
Exposure to high temperature due to limited air movements inside	Environmental	PPE	Provide least PPE to limit thermal discomfort	Reduction of PPE effecting physical discomfort	Physical
High noise emission during machining	Environmental	PPE	Provide ear muffs	Audible signals not received	Cognitive
Cannot make observations due to discomfort glare	Environmental	PPE	Provide Safety goggles	Loosing visibility over general operations	Environmental
Dangerous to touch due to high temperature	Physical	PPE	Use pair of gloves	Loose grip on tools	Physical
Machine-related auditory signals not distinguishable from each other	Psychological	Substitute	Change to Visual Signal	Need physical movements to grasp signal	Physical
Incremental change presented with digital display leading to attention lost	Psychologica l	Engineeri	Introduce warning alarm	Confusion with other alarms	Psychologica l

Tabel 4: Interdependancies of Risk controls and their impacts

5.4. Relationship between controls position in the hierarchy and their impact

Behaviour of Impact Ratio (IR) along the hierarchy was plotted and correlation was also calculated. Same exercise was done for impact ratios on Severity, Occurrence and Detection separately. Same analysis was conducted considering Environmental, Physical and Psychological risk factors separately to study individual behaviour of impact ratios on ergonomic risks of different nature. Correlation was calculated between the multiplication of impact ratio by implement ability score Vs Hierarchical Position (HP) as well. Table 5 presents the correlations calculated.

	Overall	Environmental risks	Physical risks	Psychological risks
Correlation HP Vs. IR	-0.145	0.015	0.109	-0.543
Correlation HP Vs. IRs	0.093	0.304	0.056	0.048
Correlation HP Vs. IRo	-0.104	-0.190	0.167	-0.299
Correlation HP Vs. IRd	-0.246	-0.144	-0.177	-0.422
Correlation HP Vs. IR X IMP	0.027	0.274	0.035	-0.465

Table 5: Correlation between Hierarchy position and Impact

5.4.1. Relationship between controls position in the hierarchy and overall impact

When all risk factors are considered together, -0.145 correlation noted between the control's position in the Hierarchy against the impact it creates. This means that when all ergonomisc risks are considred together, the impact of a control deminishes along the position in the Hierarchy from Elimination (possition 1) to PPE (posstion 5).

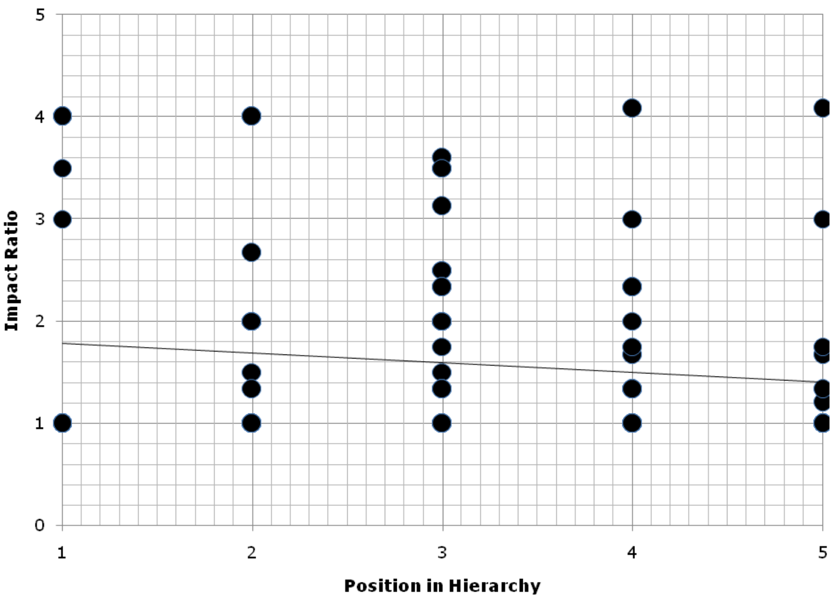


Chart 1: Relationship between controls position in the hierarchy and overall impact

However, it was noted that impact ratios under all ergonomics risks corresponding controls shows a variation of 0.88, between minimum 1 and maximum 4.08 with an average of 1.59. To have a greater understanding of the behavior variation of the impact ratio was studied under each control type. While the range lies between 1 and 4.08, variation under Hierarchy Position 1 (Elimination) shows the largest variation (1.47) in impact ratio. Variation of Impact Ration shows a gradual decline along the Hierarchy from Elimination to PPE. Average impact Ration was greatest (1.90) with the Engineering Controls (Hierarchy Position 3) while PPE (Hierarchy Position 5) showed the least average Impact Ratio of 1.28.

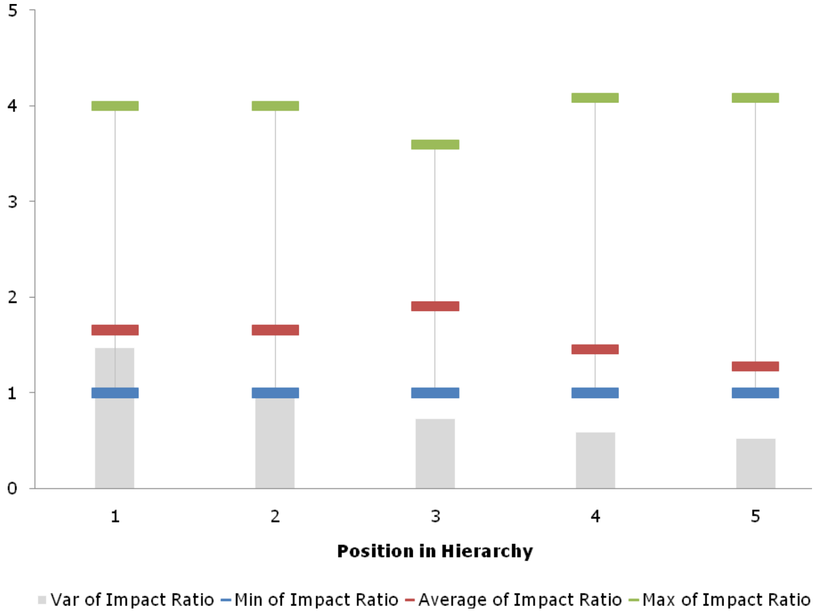


Chart 2: Position in the hierarchy and variation in impact

Impact of the control caused on three areas, Severity, Occurrence and Detection. When all the Ergonomic Risk Factors are considered together, Impact Ratio on Severity positively correlates (Correlation + 0.093) with the position in Hierarchy which mean that Severity decreases as moved from Elimination to PPE. Correlation between Impact Ration on Occurrence with the Hierarchy position is -0.104 and Correlation between Impact Ration on Detection with the Hierarchy position is -0.246. This leads to the indication that Occurrence become more possible compared to Detection as moved from PPE to Elimination.

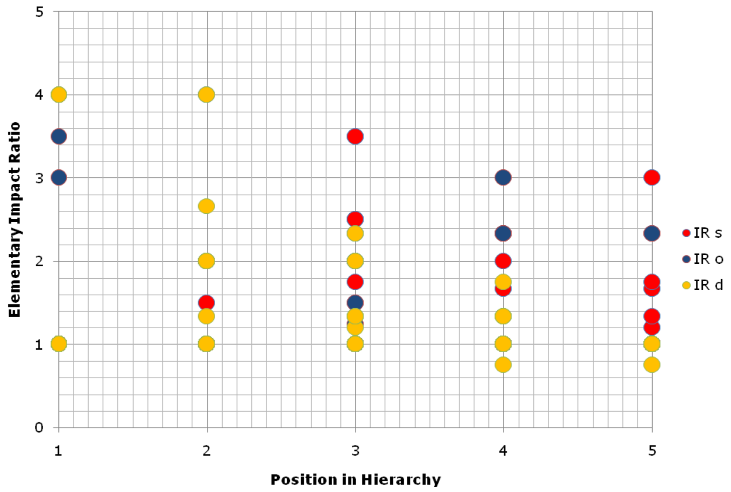


Chart 3: Position in the hierarchy and variation in impact with Severity, Occurrence and Detection

Further to studding the nature of the behaviour of Impact of controls for Ergonomic risk factors in common it would help understanding further relations if the risk factors are studied separately. Chart 4 presents the Average Impact Ratio of different controls assigned to different types of ergonomic risk factors. Discussion is continued below with reference to the behaviour of Impact for Ergonomic risk factors separately.

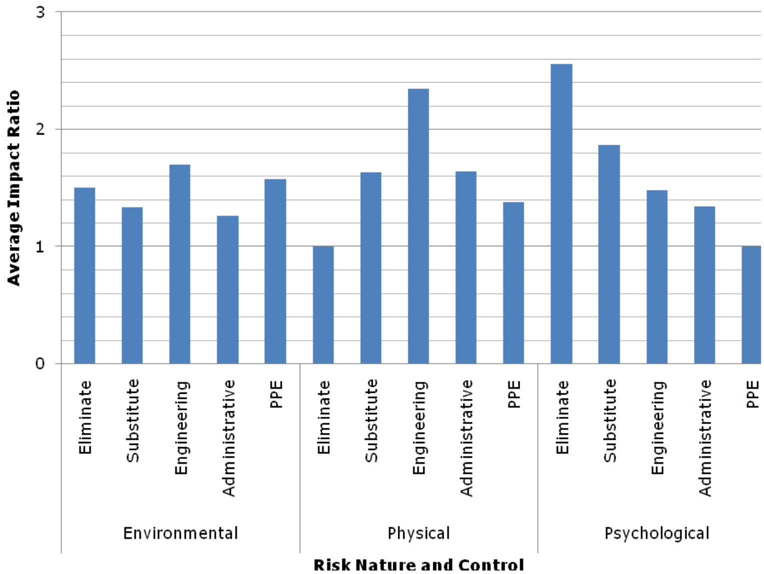


Chart 4: Average Impact Ratio for different controls of different ergonomic risk factors

5.4.2. Relationship between controls position in the hierarchy and impact on Environmental risk factors

As the correlation is calculated of the Impact Ratio against the Hierarchy position for the environmental risks only, there is no meaning full relationship reflected since the value is 0.015. Average Impact ratio is greatest with Engineering Controls (Refer Chart 4) and PPEs provide second best protection. Administrative controls show the least impact on the Environmental Risk Factors.

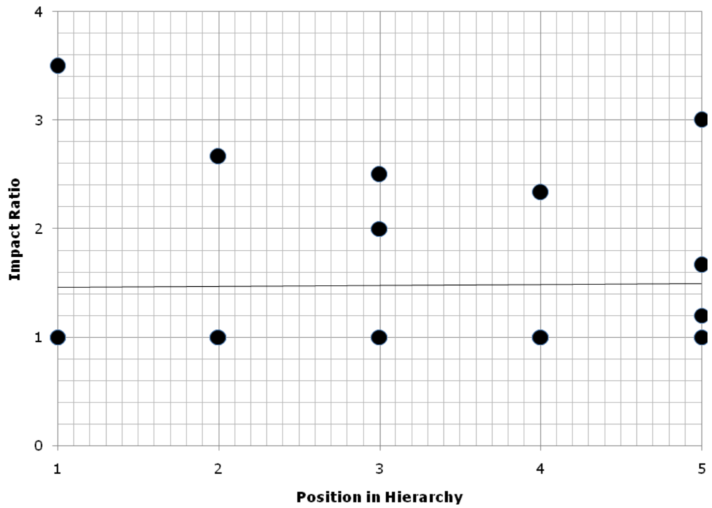
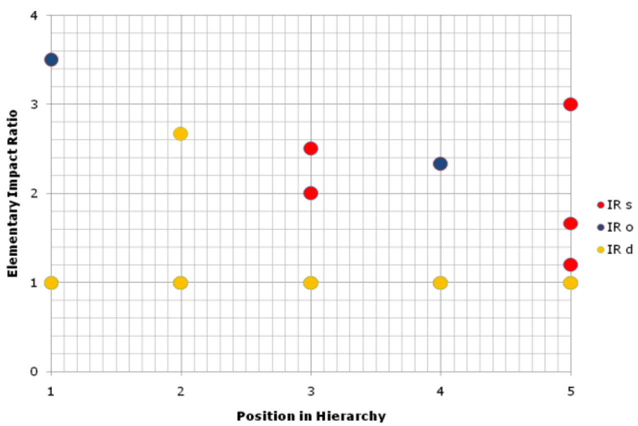


Chart 4: Impact Ratio of different controls for Environmental risk factors

When the elementary impact is considered, Impact Ratio on Severity shows a significant + correlation (+0.304) along the Hierarchy from Elimination to PPE indicating that <u>Severity</u> of Environmental risk significantly reduce as controlled attempted from Elimination to PPE. Impact on Occurrence and Detection shows small – correlation along the hierarchy.

Chart 5: Impact Ratio on Severity, Occurrence and Detection along the Hierarchy for Environmental Risks



5.4.3. Relationship between controls position in the hierarchy and impact on Physical risk factors

As per the plot on Chart 4, Average impact is highest and significant with Engineering controls for Physical Ergonomic Risks. Substitution and Administrative controls create second highest impact and Elimination shows least affective. Overall Impact ratio shows a small + correlation along the hierarchy.

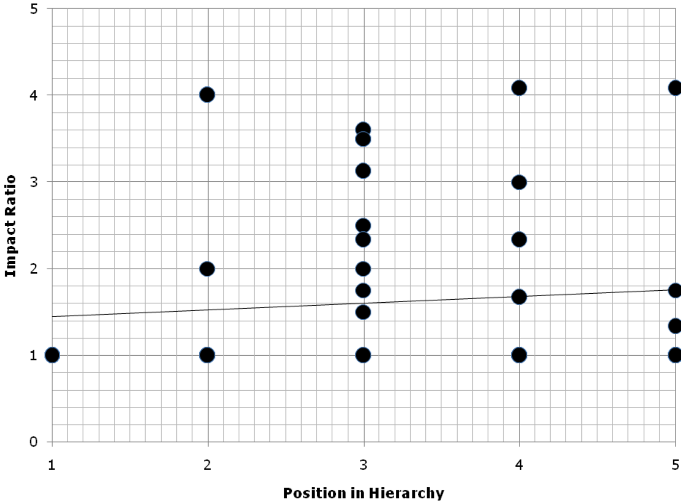
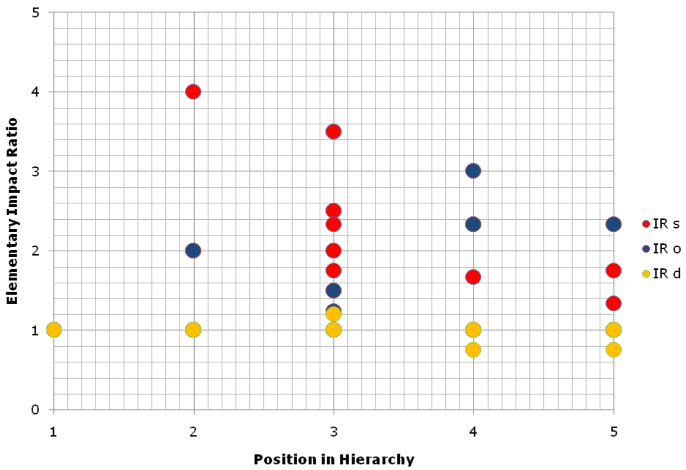


Chart 6: Impact Ratio of different controls for Physical risk factors

Elementary Impact Ration on Severity, Occurrence and Detection are not showing a significant meaning full relation along the Hierarchy since none of them exceed 0.177. Significance observation is that none of the Physical risks have been detected for possible controls to totally eliminate them.

Chart 7: Impact Ratio on Severity, Occurrence and Detection along the Hierarchy for Physical Risks



5.4.4. Relationship between controls position in the hierarchy and impact on Psychological risk factors

Overall impact of controls along the Hierarchy shows a significant negative correlation (Chart 8) with the Impact Ratio, meaning Psychological Risks become less manageable as controlled attempted from Elimination to PPE. Average Impact Ratio of 2.5 noted by means of elimination. When the elementary impact on Severity, Occurrence and Detection are considered on Chart 9 it clarifies that the strong – correlation of Detection along the Hierarchy (-0.422) influences the overall correlation to be strongly negative. This indicates that Elimination of the risk factors by improving the detection helps manage the ergonomic risk factors. Further, as psychological risk factors are studied individually, most of them studied are of cognitive nature that needs detection to be improved.

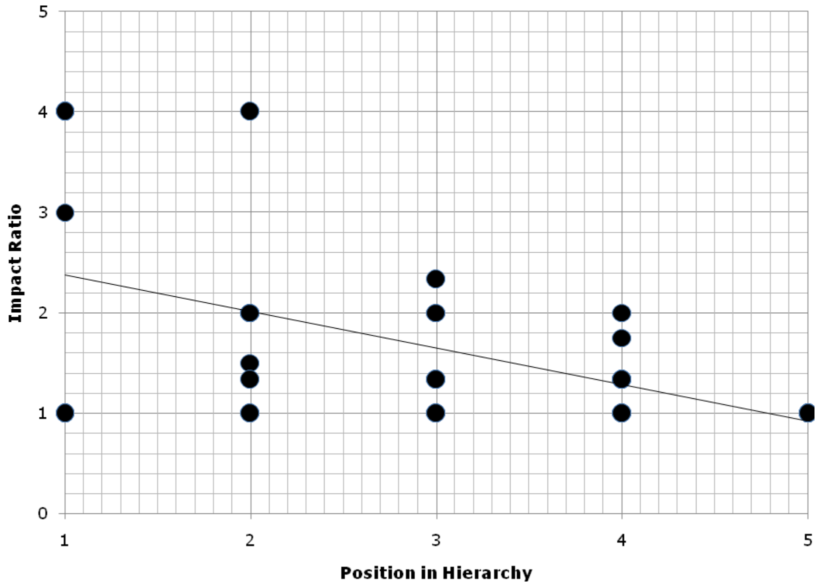


Chart 8: Impact Ratio of different controls for Psychological risk factors

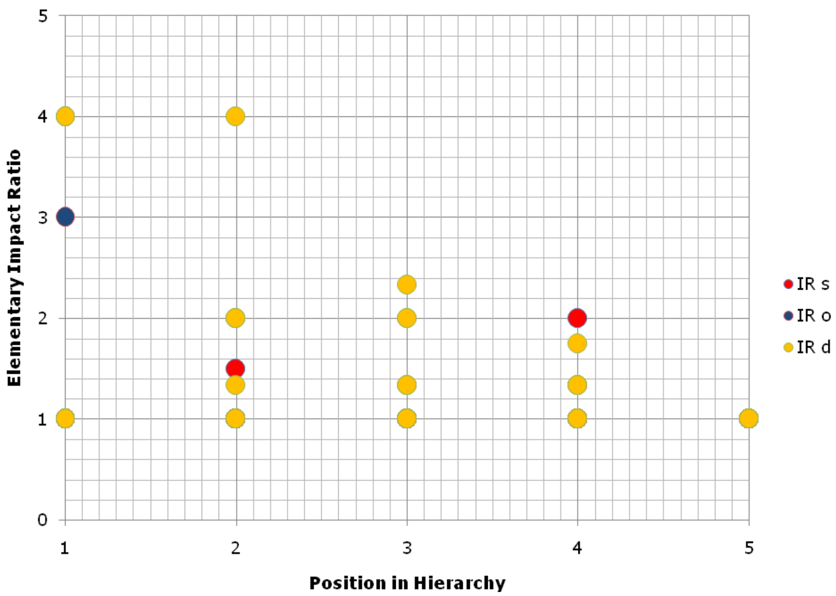


Chart 9: Impact Ratio on Severity, Occurrence and Detection along the Hierarchy for Psychological Risks

5.4.5. Relationship between controls position in the hierarchy and overall impact considering implementability score

Implementability score was made use to represent the practicability of the controls suggested under each control type. The score did not carry a reference value representation other than the order of practicability since such valuation attempt has not been developed for this study.

Introduction of Implementability ratio further dissolves the overall correlation between Impact Ratio and Position in the Hierarchy changing it to +0.027 from -0.145 (Refer Chart 9). This indicates that the practicality of the solutions discussed have a significant impact on the general acceptance over the fact that impact of controls becomes greater at the earlier stages of the Hierarchy.

However, as plotted on Chart 10, behaviour of Impact Ratio on Environmental Impact along the Hierarchy becomes very significant from +0.015 to +0.274 with the introduction of implementability ratio. As the reason is discovered it is evident that the relation is improved due to carrying high implementability score for most Engineering and PPE controls, PPE being the last choice on the Hierarchy.

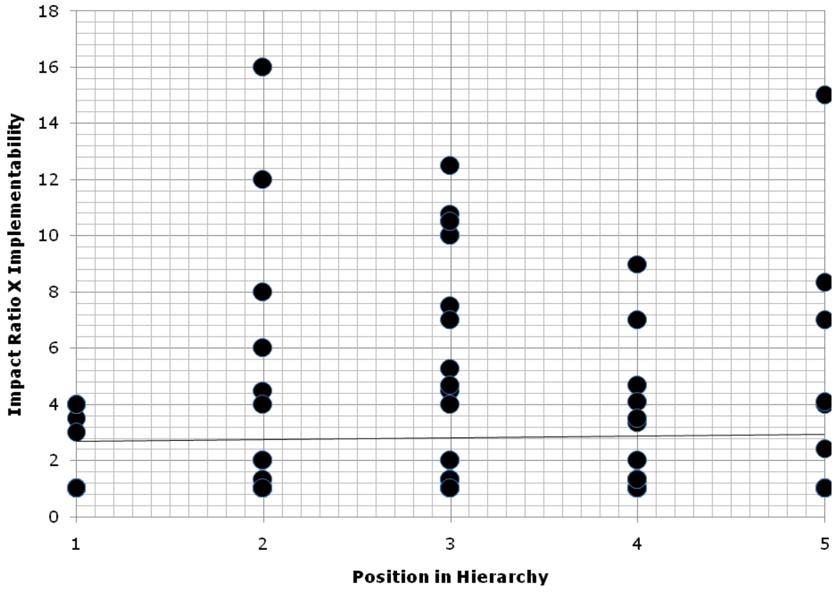


Chart 9: Impact Ratio X Implementability along the Hierarchy for all Ergonomic Risks

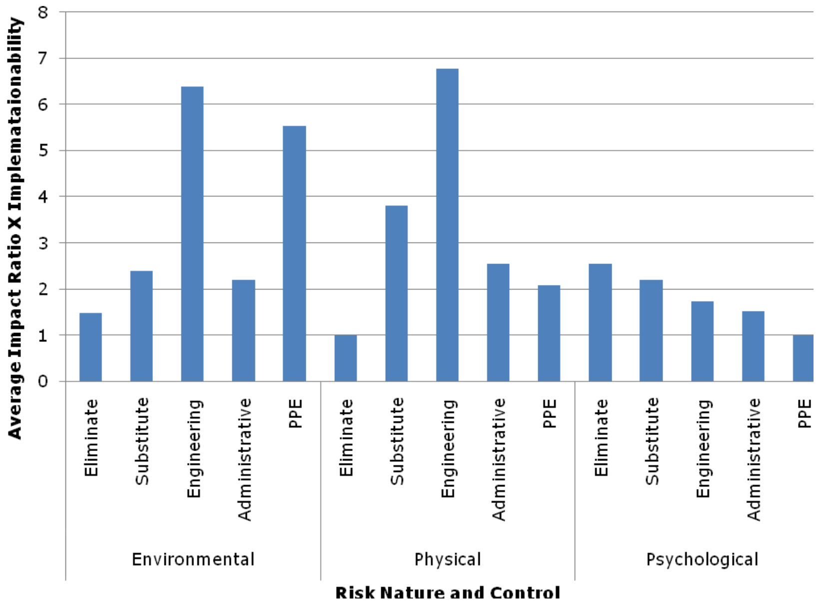


Chart 10: Impact Ratio X Implementability along the Hierarchy for different Ergonomic Risks

5.5. Visualising the Impact Rations on Severity, Occurrence and Detection of different controls for different Ergonomic Risks.

As the average impact ratios of Severity, Occurrence and Detection are plotted along the Hierarchy on Chart 11, for different ergonomic risks, it provides a visual guide to determining the sequence of consideration for "What" and "How" to control different Ergonomic Risks. For an Example, first attempt to control psychological risk would be to "Eliminate" the risk by attempting to Improve "Detection". Second choice would be to "Substitute" again to improve "Detection". Providing PPE creates no impact on Severity, Occurrence or Detection to manage Psychological Risks.

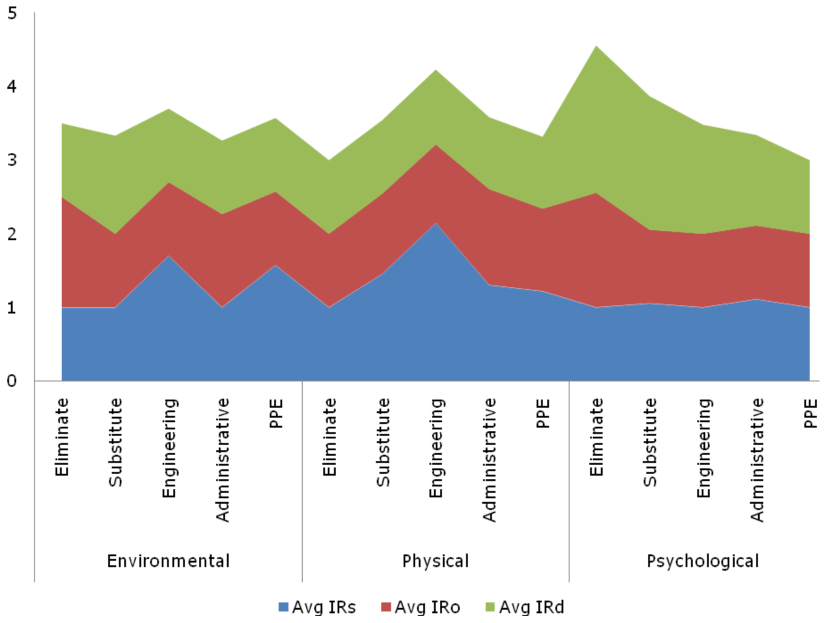


Chart 11: Visualising the Elementary Impact Rations of different controls for different Ergonomic Risks.

6. Conclusions and future work

- Impact of the controls along the Hierarchy from Elimination to PPE reduces slightly. When the practicality is considered by introducing the Implemetability Score this relation turns backward.
- When the nature of ergonomic risk whether Physical, Psychological or Environmental is considered independently, they are affected from rest of the factors as well as by the practicability of the control resulting a disturbance to gradual correlation along the Hierarchy.
- Individual risk factors of Physical, Psychological and Environmental indicated their own preferred positions in the

Hierarchy as "Engineering Controls" for Environmental risks and Physical Risks and "Elimination" for Psychological risk disturbing the overall correlation.

- Implementability score did not carry a reference value representation of the practicability of the solution but represented only the order of practicability. A meaningful quantification of Implementability would help discovering more realistic relation of impacts of practicable solutions along the hierarchy.
- For a selected maintenance operation, ergonomically affected aspect (Physical, Psychological, Environmental), Possible Controls in the Hierarchy and respective Impact rate on Severity, Occurrence and Detection resulted in a matrix that quantifies the risk and effectiveness of the control. This relationship might be used in prioritising controls from options to mitigate ergonomics risks in maintenance operation as an alternation of attempting with the order in general Hierarch.
- The study was limited to observations on 25 risk factors. Continuation of adding assessment records and recommended controls to same study model will enhance the coverage representing a more realistic decision model.

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