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ERGONOMICS AND PHYSICAL DEMAND ANALYSIS IN A CONSTRUCTION MANUFACTURING FACILITY

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Abstract: Poor workstation design in a manufacturing facility negatively impacts the health and safety of workers, which hampers productivity. A systematic tool, Physical Demand Analysis (PDA), is utilized in a case-study project to quantify and evaluate physical labour and body posture for various production line tasks in a window and door manufacturing company. This paper presents the implementation PDA focusing on the design of the PDA form template, plant observation, and ergonomic risk identification. The data collection methodology and the implementation of time studies for plant observation are described. Four main ergonomic risks are identified: static whole body posture, manual material handling, sensory problem, and awkward body postures. Detailed observation findings, risk assessment method, analysis results and suggested corresponding corrective measures with regard to these four risks are described in this paper.

1 PLANT OBSERVATION AND ERGONOMIC ANALYSIS

A well-designed workstation which takes into consideration ergonomics can ensure the health and safety of workers while improving the productivity of a manufacturing plant's production line (Deros et al. 2011). On the other hand, workstation the design of which fails to consider ergonomics often require awkward body postures for workers, which may contribute to musculoskeletal disorders or injuries. These disorders and conditions, in turn, delay the production line accordingly. Thus these stations need to be redesigned in order to avoid awkward and potentially detrimental postures for workers.

Ergonomic concerns must be considered in the design phase of construction, and this involves negotiation among the ergonomist, engineer, customer, implementer, and management team (Burns and Vicente 1999). The same can be said of manufacturing plant design, whereby worker comfort, wellness, and productivity can be upheld through proper break times and ergonomic measures.

For an existing manufacturing plant that either has not incorporated ergonomic principles in the design phase or needs to be improved or modified to enhance working condition, researchers can address these challenges by conducting observations in the plant and recommending corrective measures accordingly. Physical Demand Analysis (PDA) is a method that enables the health and safety department to comprehend the plant operation in detail for each production line and analyze the potential ergonomic risks for workers station-by-station.

1.1 Physical Demand Analysis

PDA uses a methodical process to collect data pertaining to the physical demands of a given job on specific areas of the human body. The Industrial Accident Prevention Association (2009) defines PDA as "*a systematic procedure to quantify and evaluate the physical, cognitive, and environmental demands of the essential and non-essential tasks of a job*". These documents are records, station-by-station, of all the collected physical demand data, which is obtained from plant observations. PDAs can be used as a proactive means of preventing injuries by identifying ergonomic risks, and, in response to an incident, as an aid for rehabilitation. In particular, PDAs can be used for the following purposes (Industrial Accident Prevention Association 2009):

- to assist in identifying tasks for each job, work processes, and equipment that may require further ergonomic assessment and intervention
- to assist in identifying and prioritizing safety risks
- to provide useful documents for recruitment and training workers
- to assist with job assignment and identification of appropriate modified duties for injured workers;
- to devise strategies for modifying tasks in order to prevent injuries on the job
- to provide details on job demands to health care providers and the workers' compensation boards corresponding to the locations of the company's manufacturing facilities—the Workers' Compensation Board (WCB) of Alberta and the Ontario Workplace Safety and Insurance Board (WSIB).

PDAs play a vital role in ensuring the effectiveness and efficiency of return-to-work programs. A PDA is carried out for each job, where each job consists of several tasks that are described in detail in the PDA. A typical PDA usually includes a job overview, work shift schedule, and details pertaining to meals and breaks, job rotation, personal protective equipment, critical tasks, equipment utilized, strength demands (lifting / lowering / carrying / pushing / pulling / grasping), repetitive motion requirements, body posture requirements, sensory demand, environmental conditions, and ergonomic risks. The PDA displays in a form, which has a wide range of uses in the workplace, varying from rehabilitation to injury prevention. Companies are free to select which job receives a PDA form. PDA forms should be kept up to date as a company undergoes innovation and improves its practices.

Performing a PDA can be especially difficult for highly variable, infrequent jobs. For such jobs, direct workplace observation is inconvenient, since these jobs may only be performed for short periods of time and infrequently. One solution is to use video recorders to capture footage of workers performing tasks. The videos are then consolidated and analyzed, giving the rater the ability to perform analysis as if the worker was completing one lengthy task.

1.2 Methods for Data Collection and Time Study

Different methods for collecting time data in a workplace environment can result in drastically different results. Two methods for data collection exist—subjective and objective data collection. Subjective data collection involves the gathering of data by communicating with workers, using questionnaires, and reading logs; objective data collection is carried out either by direct observation or photography / videography. Besides the associated financial burden on the employer, subjective method tends to yield inaccurate risk assessments that exaggerate instances of injury or chronic pain based on anecdotal evidence (Palmer et al. 2000). Descatha et al. (2009) similarly showed that questionnaires tend to identify a higher level of risk than what is actually present as determined through direct observation. Although questionnaires may be a less costly alternative, they fail to encompass all the potential health exposure problems (Descatha et al. 2009). In cases where the employer is interested in minimizing losses due to health and productivity risks at the expense of a lengthier study, an objective method is preferred (Palmer et al. 2000).

A study was performed by McCallig (2010) in a construction company to compare three data collection methods—questionnaire, interview, and direct observation—on estimation of exposure time to hand/arm and whole-body vibration. The study found that the interview and direct observation could provide more reliable results than self-reported questionnaires or surveys (McCallig et al. 2010). Deros et al. (2011)

carried out an observation recording video footage of a motorcycle component manufacturing plant. The video footage was found to allow ample time for observation of posture and movement of the workers. Also, face-to-face interviews were conducted to obtain better understanding of the work being done, problems faced and health concerns. Based on their observation they found that, as a result of poor ergonomic design of workstations, workers are required to frequently bend their spines and twist their necks, which further results in musculoskeletal disorder (Deros et al. 2011). Video-based observation can also be used together with technical measurements to indicate the non-neutral and extreme postures for repetitive motion leading to work-related musculoskeletal disorders (Juul-Kristensen et al. 2001). In the case study presented in this paper, direct observation and video-based observation with the support of interview and manual measurements are the primary methods selected by which to analyze ergonomic risks.

1.3 Objective

This research project has been built upon the hypothesis that the implementation of PDAs in a manufacturing construction plant enables the health and safety department to better assess job requirements, ensure that the workload is within the workers' capacity, and lower the potential risks of work-related injuries. The paper proposes a methodology to effectively process PDAs in manufacturing facilities and discusses the benefits to industry of implementing PDAs.

2 PDA PROJECT METHODOLOGY

The PDA project includes three steps: PDA form creation, plant observation, and ergonomic risk identification (see Figure 1). A PDA form is selected as the basis of ergonomic risk identification in the manufacturing plant. Developing a new custom form can have certain advantages over using a pre-existing one. A few PDA templates do exist, such as those available from the Industrial Accident Prevention Association, Occupational Health Clinics for Ontario Workers, and the Workplace Safety & Insurance Board. A new PDA template can be achieved when those physical demand factors to which workers are not exposed are omitted. Based on the framework provided by the PDA template, the PDA form specifies which job it pertains to by including job name, department line, and other basic information. A given job may or may not require a PDA, depending on the requirements of the company. Plant observation is required in order to identify tasks, work processes, and equipment that may be required.

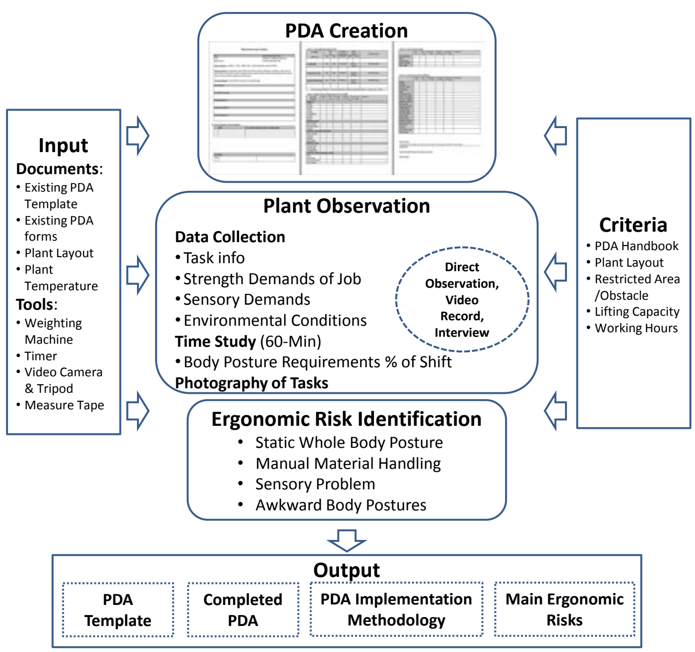

Figure 1: PDA implementation methodology

In plant observation, required information can be obtained by three approaches: data collection, time study, and photography of tasks. Direct Observation and video recording methods are selected in this methodology due to their high reliability. Interviews are also included as part of the PDA project since communication can assist external observers in better understanding the tasks being analyzed. Other data collection methods include manual measurements (e.g., use of weighting machine). Forms for the “strength demands of job”, “sensory demands”, and “environmental conditions” where frequency data is not required can be completed by this time.

The frequency and body posture requirements can be ascertained through a time study. A 60-minute time study is proposed in this methodology for cases in which most tasks involved can be completed within 30 minutes. In the time study, body postures are recorded in a spreadsheet on one-minute intervals for each job (Figure 2). A combination of direct observation and video recording observation should be used, since video cameras offer the advantage of recording hours of footage for multiple stations simultaneously. This footage is later analyzed by the research team to extract the relevant data. (Video recording, it should be noted, may be unsuitable in cases where the workers are highly mobile since the viewing angle of video cameras is limited. In addition, some stations may be found to have limited working space, resulting in problematic camera positioning. In these cases, manual / direct observation is the recommended method.) The workers should be made aware that they will be observed and informed of the nature of the work prior to observation commencing. Furthermore, in the case of video recording, observers should be cognizant of working hours and scheduled breaks in order to avoid collecting footage during breaks.

Observation	Mobility							Back			Shoulder				Neck			Elbow	Wrist		
	walk	stand	sit	climb	Crouch/squat	kneel	drive	Forward	Back	Twist	Above	Forward	Sideway	Behind	Forward	Back	Twist/Tilt	Flex/Extend	Flex/Extend	Rotate	
1																					1
2																					2
3																					3
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%																					%
Frequency																					Frequency

Figure 2: Time Study Sheet

It should be noted that “frequency” in this study is defined as the number of times a motion is repeated over a specified period of time by a worker, which can be estimated using Equation [1].

[1] Percentage of shift = (number of checkmarks in spreadsheet) / 60 × 100%

Once the percentage has been calculated for each posture, a frequency descriptor is assigned to each percentage range as follows: Never (0%), Rare (1 – 5%), Occasional (6 – 33%), Frequent (34 – 66%), Continuous (67 – 100%).

The last step is collecting photographs for each task to be inserted in the form in order to help visualize the task. Scheduling this process as the last step in the PDA project allows for the workers to become more comfortable with the research and for the observers to familiarize themselves with the production process at the plant. For those workers who decline consent for their face to appear in a photograph, the alternative is to arrange the photograph in such a way that the subject’s back is to the camera. Those who decline this option as well do not appear in any photographs of their respective workstations. In these cases the photographs are taken of the production process, tools, and materials under use but not of the worker/s. Plentiful photographs ensure accurate representation of the tasks performed and of the inherent ergonomic risks.

After the plant observation, researchers can identify ergonomic risks based on the data collected in previous processes and propose corresponding corrective measures. The objective of this process is to identify ergonomic risk factors, ensure that tasks are within the workers’ capacity and limitations, and devise corresponding corrective measures. Based on data collection and time studies, ergonomic risks can be identified. However, risk factors vary in each case study; risk factor assessment is further discussed in the case study section below. As outputs of the project, the corresponding company is delivered not only a PDA template ready for future use, but a list of current ergonomic risk for each task and corresponding suggested modifications.

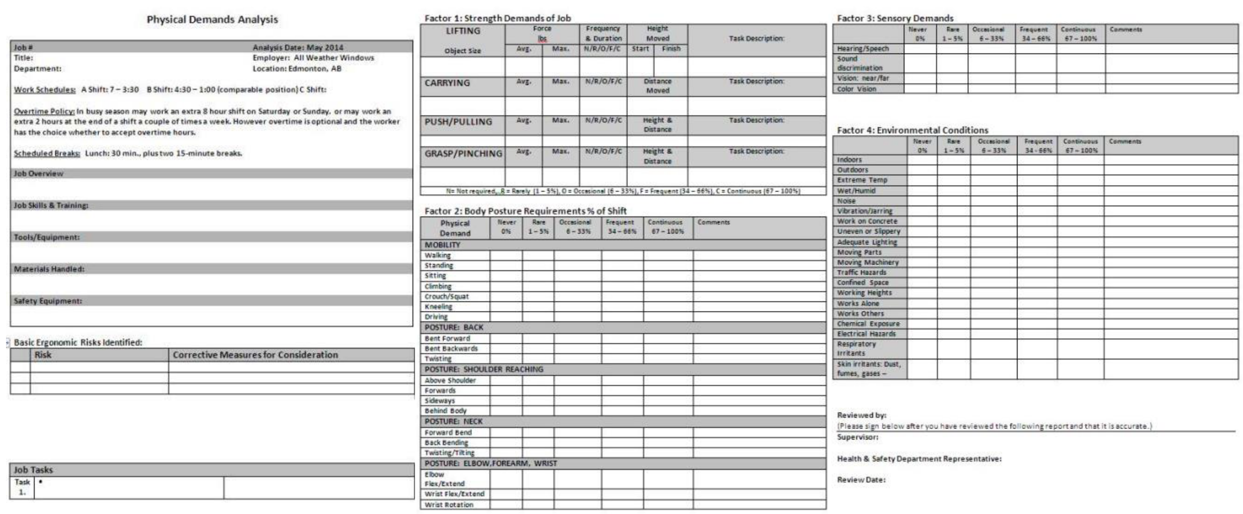
3 PDA IMPLEMENTATION

A PDA is implemented as a collaborative project between All Weather Windows (AWW)—a major window and door manufacturer—and the University of Alberta. The manufacturing facility observed in this project is located in Edmonton, Alberta, Canada. PDAs are integral to their operations. PDAs enable workers to perform duties suited to their abilities, while also assisting others to ensure that when injury incidents do occur, the company has a clear picture of worker responsibilities and how to best develop return-to-work strategies. A well-managed return-to-work program allows the company to continue production operations seamlessly while providing meaningful work opportunities for employees rehabilitating following injury. Obtaining PDAs for each job on every production line ensures that the company can work pro-actively to better promote worker wellbeing by lowering the risk of work-related injuries.

With existing PDAs outdated, unnecessarily lengthy and complicated, and not accurately representative of the current state of the plant, the company sought a PDA which reflects recent changes in the plant in terms of tasks and production line allocation, thereby necessitating the PDA revision. The objective of the case study was thus to create a new PDA template suited to completing PDA forms and identifying ergonomic risks for all workstations in the collaborating company's production facility.

3.1 PDA Template Creation

Based on the existing PDAs and a literature review regarding the content of PDA forms, the researchers develop a new template with detailed task information, basic ergonomic risk identification, strength demands of job, body posture requirements (expressed as frequency per shift), sensory demands, and environmental conditions, as shown in Figure 3. In terms of efficiency and effectiveness, the new PDA template is more practical. It is better organized (contains six tables), shorter (4-5 pages) but more informative compared with the previous PDA, which is lengthy (10-12 pages) and includes redundant content. Thus, the new PDA allows company health care personnel to quickly scan through the form and conveniently identify the primary cause of the worker's injury.


Physical Demands Analysis

Job #: Analysis Date: May 2014
Title: Employer: All Weather Windows
Department: Location: Edmonton, AB

Work Schedules: A Shift: 7 – 3:30 B Shift: 4:30 – 1:00 (comparable position) C Shift:

Overtime Policy: In busy season may work an extra 8 hour shift on Saturday or Sunday, or may work an extra 2 hours at the end of a shift a couple of times a week. However overtime is optional and the worker has the choice whether to accept overtime hours.

Scheduled Breaks: Lunch: 30 min., plus two 15-minute breaks.

Job Overview:

Job Skills & Training:

Tools/Equipment:

Materials Handled:

Safety Equipment:

Basic Ergonomic Risks Identified:

Risk	Corrective Measures for Consideration

Job Tasks

Task 1.	•

Factor 1: Strength Demands of Job

LIFTING	Force lbs Avg.	Max.	Frequency & Duration N/R/O/F/C	Height Moved Start	Finish	Task Description:
Object Size						
CARRYING	Avg.	Max.	N/R/O/F/C	Distance Moved		Task Description:
PUSH/PULLING	Avg.	Max.	N/R/O/F/C	Height & Distance		Task Description:
GRASP/PINCHING	Avg.	Max.	N/R/O/F/C	Height & Distance		Task Description:

N= Not required, R = Rarely (1 – 5%), O = Occasional (6 – 33%), F = Frequent (34 – 66%), C = Continuous (67 – 100%)

Factor 2: Body Posture Requirements % of Shift

Physical Demand	Never 0%	Rare 1 – 5%	Occasional 6 – 33%	Frequent 34 – 66%	Continuous 67 – 100%	Comments
MOBILITY						
Walking						
Standing						
Sitting						
Climbing						
Crouch/Squat						
Kneeling						
Driving						
POSTURE: BACK						
Bent Forward						
Bent Backwards						
Twisting						
POSTURE: SHOULDER REACHING						
Above Shoulder						
Forwards						
Sideways						
Behind Body						
POSTURE: NECK						
Forward Bend						
Back Bending						
Twisting/Tilting						
POSTURE: ELBOW, FOREARM, WRIST						
Elbow Flex/Extend						
Wrist Flex/Extend						
Wrist Rotation						

Factor 3: Sensory Demands

	Never 0%	Rare 1 – 5%	Occasional 6 – 33%	Frequent 34 – 66%	Continuous 67 – 100%	Comments
Hearing/Speech						
Sound discrimination						
Vision: near/far						
Color Vision						

Factor 4: Environmental Conditions

	Never 0%	Rare 1 – 5%	Occasional 6 – 33%	Frequent 34 – 66%	Continuous 67 – 100%	Comments
Indoors						
Outdoors						
Extreme Temp						
Wet/Humid						
Noise						
Vibration/Jarring						
Work on Concrete						
Uneven or Slippery						
Adequate Lighting						
Moving Parts						
Moving Machinery						
Traffic Hazards						
Confined Space						
Working Heights						
Works Alone						
Works Others						
Chemical Exposure						
Electrical Hazards						
Respiratory Irritants						
Skin Irritants: Dust, fumes, gases –						

Reviewed by:
(Please sign below after you have reviewed the following report and that it is accurate.)
Supervisor:

Health & Safety Department Representative:

Review Date:

Figure 3: New PDA template

3.2 Plant Observation

Plant observation involves data collection, time study, and photographing of tasks. The day shift is selected for the plant observation. This shift begins at 7:00 a.m. and ends at 3:30 p.m. with a 30-minute lunch break and 15-minute coffee breaks in the morning and afternoon. Before any observations are carried out, certain terminologies in the PDA form must be clarified.

A 60-minute time study is implemented. This is considered to be sufficient for most workstations, as most tasks can be completed within 5-25 minutes. Consent of the workers is obtained and efforts are made to minimize any interference with the production line work during observation. The time study observations are followed by short interviews with the workers being observed. Workers are asked to describe which aspects of their work are the most physically taxing and to explain which body parts are strained after a day's work. Information collected in these interviews is used for ergonomic risk identification.

3.3 Ergonomic Risks Identification

Based on the data collected during plant observation and the summarized documentations, the main ergonomic risks are identified. Four main ergonomic risks are described below. Some of the ergonomic risks can be prevented by taking easily implemented measures, while others may require further machinery development at the workstation.

1. Static Whole Body Posture

Most of the workstations require prolonged standing throughout the workday, which leads to back and foot pain. To counteract this, anti-fatigue matting or shoe insoles can significantly decrease the pressure placed on the spine and feet. Providing footrests for the workers is another effective method to decrease the strain that contributes to back and foot pain.

Table 1: Risk identification for static whole body posture

Risk Factors	Risk	Findings	Recommendations	Corrective Measures for Consideration
Static whole body posture	Prolonged standing			Provide anti-fatigue matting or insoles;
				Provide footrest for workers to have a rest while standing

2. Heavy Material Handling

Workers are required to lift / push / pull heavy products manually without the aid of wheeled carts. These actions pose ergonomic risk to the back and shoulders. Heavy lifting also occurs in various production lines. The Infrastructure Health & Safety Association (IHSA) has provided a general guide for identifying ergonomics-related hazards (IHSA, 2014). In terms of manual material handling tasks, two worker weight capacity tables are provided by IHSA. If the profiles to be lifted exceed the worker weight capacity as outlined in these tables, the worker will be exposed to a dangerously high risk of injury. These two tables present the lifting/lowering weight limits for males only and for females only or both males and females. Based on this guideline, the ergonomic risks related to material handling can be identified for various tasks.

However, the weight capacity also varies based on four factors: (1) the relative distance the object is to be moved (far/close), (2) the size of the profiles (long/short), (3) the working height (hands end below knuckle height / hands end between knuckle and shoulder height / hands end above shoulder height), and (4) the approximate duration of the move (15 seconds, 1 minute, 2 minutes, 5 minutes, 30 minutes, or 8 hours). The distance to be moved and the working height are obtained from observation, and the description of the profile provides the dimensions and weight. The duration of the move can be estimated based on the shift working hours and the observation results. Shift A is from 7:00 a.m. to 3:30 p.m., and shift B is from 4:30 p.m. to 1:00 a.m., with a 30-minute lunch break and two 15-minute coffee breaks per day. Therefore, the total working hours per shift is 7.5 hours. With the results of the 60-minute time study, the weight limitations for manual lifting can be calculated using Equation [2]. By comparing the results calculated using this equation against the numbers given in the two IHSA tables (IHSA, 2014), the potential high-risk exposure tasks can be identified.

[2] $t_c = T_s \times t \times F$

Where,

T_s is the working hours within one shift

t is the observation time

F is the frequency (%) of lifting/pushing/pulling within the observation time

Table 2: Risk identification for manual material handling

Risk Factors	Risk	Findings	Recommendations	Corrective Measures for Consideration
Manual material handling	Manual material lifting/pushing/pulling: back/shoulder		To be investigated	Provide lifting machine for heavy doors and windows
				Direct transfer material/items to machine/cart;
				Switch task;
				Work with others;

The risk and corresponding corrective measures are given in Table 2. The use of a lifting machine to make this task semi-automated should be explored. A direct transfer and feeding machine to transfer the profiles from the cart to the machine or from the machine to the cart would be an even more proactive, albeit more costly, measure. The simplest measure, which the organization can implement immediately, is to stagger the tasks among workers so that particular workers are not disproportionately exposed to ergonomic risks.

3. Sensory risks

The third type of ergonomic risk identified from the observations is sensory risks, including eye fatigue and hand or arm vibrations. As can be seen in the photograph in Table 3, installation requires workers to locate pre-drilled marks in order to install the hardware on the sash. However, this task is difficult for workers, who may have to strain their eyes in order to visually locate the pre-drilled holes. From the researchers' observation, workers will additionally measure the installation positions manually in order to install the hardware accurately. To overcome these difficulties, an auto-colour marking machine should be used for the predrilled marks, and the accuracy of the markings should be improved so that there is no need to measure manually. The auto-colour marking could be added to the welding machine or designed as an independent machine.

Another sensory problem has to do with hand or arm vibration. An array of tools is utilized in each production line. For many of these tools, such as chop saws, power drills, pneumatic staple guns, and air guns, the worker is exposed to a considerable amount of vibration during operation, with frequent use posing a serious health hazard. Carpal tunnel syndrome is one condition that may result from exposure to this hazard (Health and Safety Executive, 2014). The symptoms may include only moderate pain, white fingers, and sleep disturbance, but in more serious cases it may lead to numbness and loss of strength in the hands, among other symptoms (Health and Safety Executive, 2014). To prevent the onset of Carpal tunnel or other conditions or injuries, two corrective measures are recommended. One is to provide tools and equipment at the workstations, which minimize worker exposure to hazardous vibration. The other is to limit the duration of exposure to this type of hazard for a given work, which can be achieved, (as with risk due to lifting of heavy materials), by staggering the work assignments so that no particular worker is disproportionately assigned to activities which pose this type of ergonomic risk.

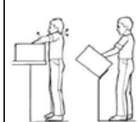
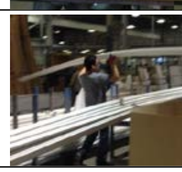
Table 3: Risk identification for sensory risks

Risk Factors	Risk	Findings	Recommendations	Corrective Measures for Consideration
Sensory	Eye fatigue: e.g. Figure out the position of installing hardware on sash		To be investigated	Auto-colour marking machine
	Hand/arm vibration		To be investigated	Provide the proper equipment; Limit the time that workers are exposed to vibration

4. Awkward body postures

Awkward body posture is the main ergonomic risk identified in the manufacturing facility. Postures are categorized into five groups (Table 4): (i) back/neck bent forward or shoulder reaching forward; (ii) reaching above shoulder; (iii) back backward bending; (iv) kneeling, crouching/ squatting; and (v) elbow, wrist flex/extension.

Table 4: Risk identification for awkward body postures

Risk Factors	Risk	Findings	Recommendations	Corrective Measures for Consideration
Awkward body postures	Back/neck bent forward, shoulder reaching forward			Adjust the height of the machine, computer, working stations Place working table next to hardware or place working station together Provide a lifter or tilter for the items
	Reaching above shoulder (e.g. Profiles transfer from cart to machine table (transfer overhead))		To be investigated	Make sure that the profiles are in proper location, no need to be transferred overhead or rotated
	Back backward bending (e.g. Foot pedal too close to machine)	 	To be investigated	Bring the foot pedal away from the machine or place it near the computer
	Kneeling, Crouching/Squatting	 	To be investigated	Ergo-auto-lift frame Provide kneeling pad
	Elbow, Wrist Flex/Extension			Adjust the height of machine/working station Provide proper tools

1.1. Back/neck bent forward, shoulder reaching forward

Whenever a worker needs to reach an item at the workstation, their back bends forward and shoulders reach forward. The neck is also strained by installations completed on a flat table. Based on the time study, the frequency of each posture can be obtained and further analyzed with regard to ergonomic risk. There are also various measures that can be taken to correct a worker's posture. First, the height of the machine, computer, or working table can be adjusted to minimize muscle strain. Due to the varying heights of employees, there is no ideal height for these components. Rather, the ideal scenario is for the heights of these working surfaces to be adjustable to the height of the worker. Such a measure is beneficial in terms of both health/safety and productivity. A second corrective measure is to locate the workstations as close as possible to one another and the profiles for installation as close as possible to the relevant workstation. Third, providing a lifter or tilter for the hardware container at each workstation can ease access to hardware by workers during installations.

1.2. Reaching above shoulder

For instance, large and long window frame profiles are used in three workstations in the organization, which requires workers to reach above the shoulders, rotating and locating the profiles to the cutting machine. As shown in the photograph in Table 4, the profiles are custom designed. However, due to the fact that the profiles are not placed in the proper position, workers must lift the profiles up and transfer them overhead. The profiles are symmetrically cut in pairs and, as a result, workers must rotate the profiles in the same direction before positioning them overhead. Considering the large number of profiles a given worker will handle at the workstation in a given shift, reducing or eliminating the need for manual overhead transfer or rotation can lower ergonomic risk while significantly improving productivity. This can be achieved through improved inventory allocation and management.

1.3. Backward bending of the back

Backward bending of the back occasionally occurs at some workstations, such as the punching and welding station. For instance, when the foot pedal is too close to the punching and welding machine, the worker must step on the foot pedal while bending backward in order to avoid injury through contact with the machine. However, this posture involves ergonomic risk of back pain. The simplest way to address this issue is to locate the foot pedal away from the machine but close to the worker. Alternatively, a hand-operated button could be programed to control the operation of the welding and punching machine.

1.4. Kneeling, crouching/squatting

There are also situations that require workers to kneel, crouch, or squat to complete a task. For example, product assembly tasks in the display line must be finished on the ground (refer to the first photograph in fifth row of Table 4 for kneeling posture). Frequent kneeling causes pain and strain in the low back and knees and involves a high risk of developing serious muscle and joint problems. Providing a kneeling mat is the simplest measure to protect workers' knees. On the other hand, for the glazing task (refer to the second photograph in the fifth row of Table 4 for crouch/squat posture), the tops of small windows and the bottoms of large windows are below the height at which glazing can be completed from a standing position, so crouching or squatting is necessary. Accordingly, the organization should invest in an ergo-auto-lift frame, which not only holds the window during glazing, but also raises or lowers the window automatically according to the comfortable working height for the worker. The same measure can be taken for other cases in which workers are assuming a crouching or squatting posture.

1.5. Elbow, wrist flex/extend

A worker occasionally needs to twist their wrist and elbow as part of a task, which may cause pain and strain. Adjusting the height of the workstation components (i.e., tables, computers, and machines) can help to solve this problem. In addition, as indicated in the photographs, using better-designed pliers, which can themselves bend to a certain degree, will minimize the need to twist the wrist.

4 CONCLUSION, CHALLENGES, AND RECOMMENDATIONS

Ergonomic analysis can be achieved after carrying out plant observation and completing the PDA project. As a result of this initiative, health care personnel in the organization's health and safety department are better informed about the job requirement and better able to determine proactive measures to mitigate potential risks. It also assists with worker recruitment and allocation. After implementing PDA in the manufacturing plant, modifications can be made in the interest of worker safety and production line productivity.

In the case project, as the project progressed some challenges were encountered, such as some workers' reluctance to cooperate with the research being carried out. Clarifying with the workers the purpose of the PDA, its importance, and the various potential uses of the PDAs served to overcome this challenge. With respect to the time studies in particular, some limitations of video recorders (e.g., battery life, view angle, etc.) were encountered. Manual observations could thus be used to supplement the video recording observation. Meanwhile, for cases in which the operators are highly mobile and the field of view of the video recorders is not sufficient, manual observation is also used. Alternatively, a video recorder with a wider angle of view enables observers to capture multiple workstations at once.

5 FUTURE STUDY

The paper has proposed a methodology to implement PDA in manufacturing facilities. The project involves plant observation, completion of PDA forms, and ergonomics risk identification with corresponding corrective measures. In future studies, different risk assessment methods can be applied based on the same data collected from the observations in order to improve the accuracy of the ergonomic risk assessment. Moreover, it is recommended that the corrective measures be implemented and another PDA be completed comparing the ergonomic risk reduction between two versions of PDAs. It is also recommended that further investments be made in semi-automated machinery to reduce labour-intensive work and mitigate ergonomic risks.

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