Section: Research Paper

DESIGN OF ENGINEERING CONTROLS TO REDUCE ERGONOMIC RISK OF THE MANUAL COFFEE BEAN MIXING PROCESS

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Abstract— Ergonomics is a scientific discipline that is focused on providing fit and suitable design of the human and work environment based on the individual's qualities and attributes. Its major objective is that man-made tools, machines, equipment, devices, and environment should enhance and upgrade, explicitly and implicitly, the welfare, safety and well-being, and performance of an individual or group of people.

Poor workplace or design leads to fatigued, frustrated and hurting workers. This rarely leads to the most productive worker. More likely, it leads to a painful and costly injury, lower productivity and poor product quality.
This study aimed to reduce and/or eliminate the ergonomic risk factors present in mixing coffee beans at Kape at Kakao ng Batangas that leads to low productivity and unmet demands of customers.

The working conditions at Kape at Kakao ng Batangas poses safety and health issues which affects the performance of the workers. According to the owner, 4/6 workers have been recorded of absenteeism per month due to low back pain. They have also recorded 2 complaints on wrist pains and 3 on upper extremities such as shoulder and neck pains. The discomfort workers are experiencing leads to producing only 20 sacks of mixed coffee beans weighing 65 kg each per week. This resulted to 15-20 sacks unmet demand of customers of Kape at Kakao ng Batangas which is considered as loss profit of the company.

The result showed that majority of the tasks performed by the workers are not ergonomically designed thus, they experienced discomfort and pain during and after the working hours. Discomfort and pain could lead to injury and they may suffer to MSDs. The REBA presented that majority of workers were under high risk levels. The RULA showed that majority of the workers were under high risk levels also and required immediate change. It was concluded that the process has lack of ergonomics awareness. Majority of the workers were performing the tasks with awkward postures. Using RAMP, the researchers were able to identify and assess physical ergonomics risk factors in manual lifting, holding, pulling or pushing loads. Cornell Musculoskeletal Disorder Questionnaire (CMDQ) was also used to determine the body parts that experience pain and discomfort due to awkward postures made during the tasks.
After the evaluation, engineering controls through an ergonomically designed coffee bean mixing machine was proposed to address the risk factors associated in the current mixing process and will help improve the workers' productivity.

Index Terms—*Ergonomics, Engineering Controls, Risk Assessment, Work-related Musculoskeletal Disorders*

I. INTRODUCTION

Ergonomics is a scientific discipline that is focused on providing fit and suitable design of the human and work environment based on the individual's qualities and attributes. Its major objective is that man-made tools, machines, equipment, devices, and environment should enhance and upgrade, explicitly and implicitly, the welfare, safety and well-being, and performance of an individual or group of people [17].

The goal of ergonomics is to reduce the worker's exposure to work hazards. A hazard is defined as a physical factor within your work environment that can harm your body. Ergonomic hazards include working in awkward or uncomfortable postures and using excessive force or high repetition to complete a task. The best ergonomic solutions will often improve productivity. By designing a job to allow for good posture, less exertion, fewer motions and better heights and reaches, the workstation becomes more efficient.

To identify the risk factors associated with a given task, risk assessment should be performed. Risk assessment is the process of identifying and classifying the risk levels for work related musculoskeletal disorders [19].

Reference [8] shows that the health and safety regulations and guidelines require to eliminate the risk or to reduce the exposure by means of engineering and administrative controls. Based on the OSHA guidelines, hierarchy of controls should be observed in addressing the risk. Engineering controls are considered as the priority in providing control measures. They eliminate or reduce exposure to a physical hazard through the adoption or substitution of engineered machinery and equipment.

The injuries incurred by workers can be detrimental to both workers and industry. Workers who injured will reduce the performance of the work and the productivity of the industry. The application of ergonomic principles would help to increase performance and productivity, but mostly help a human operator or worker to be comfortable and secure.

Kape at Kakao ng Batangas is a small-scale firm that caters coffee-bean roasting to the coffee farmers in Lipa City. The company still employs the conventional process of mixing different variety of coffee prior to roasting. Previously, Kape at Kakao ng Batangas was solely engaged in plain buy and sell of coffee beans. But years after, they provide services for their customers such as milling, roasting, and grinding.

Because the firm provides quality products and great service, many customers and even small business enterprises avail their products particularly the mixed coffee beans. Customers within and outside the province patronized the firm's products and services. Through the years, the customer demand increases because of its popularity in the coffee business. However, the firm is unable to meet the demand due to constraint in capacity.

At present, the company sells and accepts bulk orders of coffee beans based on the workers' capacity to produce the desired product. The process of mixing the coffee beans limits the workers to produce order. Since then, the workers manually mix variety of coffee beans on the floor with the use of shovels. The process takes place every Saturday with eight working hours. The mixed coffee beans are then placed in a sack that weighs sixty-five kilograms per sack. The workers carry the sack of beans to the weighing scale to ensure that the desired weight is obtained. This conventional process cause discomfort to the workers which may lead to musculoskeletal disorders (MSDs), thus, may result to low productivity. The Work-related Musculoskeletal Disorders (WMSDS) that may be obtained by the workers from the manual mixing are awkward postures, wrist pains, low back pain, and carpal tunnel syndrome.

The working conditions at Kape at Kakao ng Batangas poses safety and health issues which affects the performance of the workers. According to the owner, 4/6 workers have been recorded of absenteeism per month due to low back pain. They have also recorded 2 complaints on wrist pains and 3 on upper extremities such as shoulder and neck pains. The discomfort workers are experiencing leads to producing only 20 sacks of mixed coffee beans weighing 65 kg each per week. This resulted to 15-20 sacks unmet demand of customers per week of Kape at Kakao ng Batangas which is considered as loss profit.

This study, therefore, seeks to eliminate MSDs associated with the manual mixing of coffee beans to increase productivity and meet the customers' demand. The researcher intends to propose a design of mixer which will provide ease and efficiency in the mixing process.

II. MATERIALS AND METHODS

The purpose of the study is to formulate a design of equipment that will help reduce the risks of work-related musculoskeletal disorders among the workers of Kape at Kakao ng Batangas. The study aimed to provide engineering controls to address the risk factors associated with the current mixing process of coffee beans. To achieve the goal of the study, the researcher used applied type of research.

Reference [5] shows that applied research systematically uses high quality research standards and state of the art methods and tools to develop practical solutions for real world social problems faced by an organization and individuals. Applied research is beneficial to leaders who are concerned with improving their organizations' efficiency through identifying obstacles for higher performance.

The owner of the business is included as a research respondent who provided information and relevant data for the study. In addition, six workers of Kape at Kakao ng Batangas were also included as research participants. These workers were mainly involved in the mixing process up to bagging the coffee beans. The study needed to obtain anthropometric measurements of 100 male samples including the workers. These measurements were used to formulate the machine design.

The researcher used different tools and instruments to gather data and information. The anthropometer was used to obtain the anthropometric measurements such as the elbow height which is used to identify the ideal height of the proposed machine. Digital goniometer was used to measure the angles of the body parts needed in RULA and REBA analysis. Standardized ergonomic assessment forms were used to assess and evaluate how the workers perform the assigned work activities, and therefore identify associated ergonomic risk factors. Stopwatch was also used to measure the amount of time it takes for each of the tasks. To visualize the design of the proposed mixer, AutoCAD and machine simulation were used. More importantly, the following ergonomic assessment tools were used:

a. Manual Handling Assessment Charts (MAC)

III. The Manual Handling Assessment **Charts** tool was developed to help the user identify high-risk workplace manual handling activities and can be used to assess the risks posed by lifting, carrying, and team manual handling activities. It is designed to help understand, interpret, and categorize the level of risk of the various known risk factors associated with manual handling activities. It incorporates a numerical and a color-coding score system to highlight high-risk manual handling tasks [21].

This tool was used to assess the risk associated with the tasks of getting, weighing, and storing mixed coffee beans.

b. Rapid Entire Body Assessment (REBA)

The Rapid Entire Body Assessment tool uses a systematic process to evaluate whole body postural MSD and risk associated with job tasks. The REBA was designed for easy use without the need for an advanced degree in ergonomics of expensive equipment. The worksheet page is used to evaluate required or selected body posture, forceful exertions, type of movement or action, repetition, and coupling [30].

c. Rapid Upper Limb Assessment (RULA)

The Rapid Upper Limb Assessment (RULA) was developed to rapidly evaluate the exposure of individual workers to ergonomic risk factors associated with upper extremity MSD. The RULA ergonomic assessment tool considers biomechanical and postural load requirements of job tasks/demands on the neck, trunk and upper extremities [31].

RULA and REBA were used to assess the risk factors associated with all the tasks of mixing coffee beans. A thorough analysis of the

awkward postures of the upper and lower extremities were conducted using these tools.

d. Quick Exposure Check (QEC)

The Quick Exposure Check is a widely used instrument assessing risks for work-related musculoskeletal disorders. It was designed to assess exposure to work-related musculoskeletal risk factors affecting the back, shoulder/arm, wrist/hand, and neck.

This tool was used to assess risk factors associated with the process of mixing coffee beans. A scoring range of risk factor combinations for specific body regions and other ergonomic concerns was used in the analysis.

e. WISHA Lifting Analysis

The WISHA Lifting Calculator is an adaptation of the Revised NIOSH Lifting Equation, which is based on scientific research on the primary causes of work-related back injuries. It can be used to perform simple ergonomic risk assessments on a wide variety of manual lifting and lowering tasks and can also be used as a screening tool to identify lifting tasks which should be analyzed further using the more comprehensive NIOSH Lifting Equation.

f. NIOSH Lifting Equation

The NIOSH Lifting Equation is a tool used by occupational safety and health professionals to assess the manual material handling risks associated with lifting and lowering tasks in the workplace. The main output of the NIOSH lifting equation is Recommended Weight Limit (RWL) which which defines the maximum acceptable weight (load) that nearly all healthy employees could lift over the course of an eight-hour shift without increasing the risk of musculoskeletal disorders (MSDs) to the lower back. In addition, a Lifting Index (LI) is calculated to provide a relative estimate of the level of physical stress and MSD risk associated with the manual lifting tasks evaluated.

g. Risk Assessment and Management Tool for Manual Handling Proactively (RAMP)

The Risk Assessment and Management Tool for Manual Handling Proactively (RAMP) is consists of checklist and assessment tool which can be used to assess physical risk factors associated with manual handling activities in the production industry. The tool provides guidance for action plans and valuations to promote improvement of occupational health and safety work at company level.

h. Cornell Musculoskeletal Discomfort Questionnaire (CMDQ)

The Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) is a 54- item questionnaire containing a body map diagram and questions about the prevalence of musculoskeletal ache, pain, and discomfort in 18 regions of the body. The subjects wrote values of height and body weight themselves and the body mass index was calculated.

IV. RESULTS AND DISCUSSIONS

Table I
Awkward Postures and Its Risk Factors

Process	Risk factors
Getting coffee beans from the storage	Force exertion, load/weight frequency,repetitive activities, awkward postures
Pouring coffee beans on the floor	Awkward posture, load/weight frequency, and repetitive movements
Mixing of coffee beans	Repetitive movements, forceful exertion, awkward postures such as neck and torso twisting and sideways bending
Bagging and Weighing	Load/weight frequency, Forceful exertion, power and pinch grip in the container and in the sack, repetitive movements such as bending and twisting of neck and torso (more than 60°), shoulder abduction, and extension and flexion of wrist

Storing mixed coffee beans	Repetitive movements, awkward postures such as torso twisting and sideways bending, grip on the load

Table I shows the ergonomic risk factors including awkward postures exhibited by the workers while performing the assigned tasks. The manual material handling of loads posed hazard to the workers which increase the risk of musculoskeletal injury. Each of these risk factors may independently contribute to the development of musculoskeletal disorders, the risk is greater if several risk factors are present at the same time.

Factors that increase the risk of injury include the load being too heavy, large, difficult to grasp or unstable, the task being too exhausting or involving awkward postures or movements, and sudden application of force. Thus, it can result in fatigue, and lead to injuries of the back, neck, shoulders, arms, or other body parts. These injuries could be neck, upper limb, lower limb disorders, back pain, or back injuries.

The major workplace ergonomic risk factors are forceful exertions, repetitive/sustained awkward postures and high task repletion. Moreover, high task repetition when combined with other risk factors such as high force and/or awkward postures, can contribute to the formation of MSD. Hence, ergonomic intervention should be implemented to address the problem.

Table II
Summary of Manual Handling Assessment Chart (MAC)

Process	Risk factors	Color Band	Interpretation	Remarks
Getting of coffee beans from the storage	Load/weight frequency	**Purple**	Upper arms angled away from torso, torso bent forward, hands between knee and floor, torso both twisted and bent sideways, and palm, pinch fingertip grip or force used to keep items together	Medium level of risk to high level of risk. Change must be implemented.
	Hand distance from the lower back	**Amber**		
	Vertical lift zones	**Amber**		
	Torso twisting and sideways bending	**Red**		
	Postural constraints	**Green**		
	Grip on the load	**Red**		
Weighing coffee beans	Load/weight frequency	**Purple**	Upper arms angled away from torso, torso bent forward, hands between knee and elbow height, torso both twisted and bent sideways, no handles or handhold areas	Low level of risk to high level of risk
	Hand distance from the lower back	**Amber**		
	Vertical lift zones	**Green**		
	Torso twisting and sideways bending	**Red**		
	Postural constraints	**Green**		
	Grip on the load	**Red**		
Storing mixed coffee beans	Load/weight frequency	**Purple**	Upper arms angled away from torso, torso bent forward, hands between knee and floor, torso both twisted and bent sideways, and palm, pinch fingertip	Medium level of risk to high level of risk. Change must be implemented.
	Hand distance from the lower back	**Amber**		
	Vertical lift zones	**Amber**		
	Torso twisting and sideways bending	**Red**		
	Postural constraints	**Green**		

	Grip on the load	**Red**	grip or force used to keep items together	

Table II shows the summary of results of the Manual Handling Assessment. The MAC score sheet has four color bands, G (green), A (amber), R (red), and P (purple). Green signifies a low level of risk, Amber is at medium level of risk, Red is at high level of risk, and Purple is at very high level of risk. Each color has its own corresponding numerical score depending on the given postures.

Getting and storing coffee beans shows the same result for lifting the sacks filled with beans. For the load weight/ frequency, the color band is purple with a numerical score of 10. The hand distance from the lower back and vertical lift zones have the same color band of amber and a numerical score of 3 and 1. The torso twisting, and sideways bending has red band with a score of 2. The postural constraint is 0 with a color band of green. Lastly, the grip on the load has red band with a score of 2. The total score for these two tasks is 18. The two tasks are at medium level to high level of risk where necessary change must be implemented.

For assessments made in weighing sacks of coffee beans, the load weight/frequency has purple band with a score of 10. The hand distance from the lower back has amber band with a score 3. Vertical lift zones and postural constraints have green with a score of 0. The torso twisting and sideways bending has red band with a score of 2. Grip on the load has red band with a score of 2. The total score for this task is 17. The task is at low level of risk to high level of risk.

MAC is dedicated to assessing load resulting from manual handling. Manual handling is another type of task that can increase the risk of developing musculoskeletal disorders (MSDs) and need to be considered [40].

Table III
Summary of Rapid Entire Body Assessment (REBA)

Process	Score	Awkward Postures	Risk Factors
Getting coffee beans from the storage	14	side bending of trunk and neck, back extension, abduction of upper arm, rising of shoulder (out of the neutral range position), and twisting of wrist	Poor grip on the sack, improper lifting of sacks, too heavy to lift, and bending while lifting causes several problems for the back
Pouring coffee beans on the floor	13	trunk bending, neck is twisted, shoulder extension, and flexion and extension of wrist	Slightly bent neck, poor grip on the sack, and extended wrist while lifting
Mixing coffee beans	13	side bending of trunk and neck, leg bending of about 60°, abduction, extension, and flexion of shoulder, upper arm abduction, and twisted wrist	High task repetition and excessive exertion of force
Bagging of coffee beans	13	neck and trunk bending, abduction, extension and flexion of shoulder, and extension and flexion of elbow and wrist	Repetition of trunk bending and over exertion of force while filling up the sack
Weighing of coffee beans	14	twisting about waist, lateral bending,	Poor grip on the sack, too heavy to

		shoulder extension, and extension of wrist	lift,and excessive exertion of force
Storing mixed coffee beans	13	back extension, neck and trunk side bending, shoulder abduction, knee bending, and extension and flexion of wrist	Poor grip on the sack, improper lifting of sacks, too heavy to lift, and bending while lifting causes several back problems

The Summary of Rapid Entire Body Assessment (REBA) is shown in Table III. The final REBA score for the first process is 14 which indicates a very high risk where change must be implemented to reduce or eliminate risks of MSDs. This is due to awkward postures exhibited by the workers such as side bending of trunk and neck, back extension, abduction of upper arm, rising of shoulder (out of the neutral range position), and twisting of wrist. Pouring coffee beans obtained a score of 13 which indicates a very high risk to injuries. Change must be implemented to reduce or eliminate the risks of developing MSDs. The awkward postures exhibited by the workers were trunk bending, neck is twisted, shoulder extension, and flexion and extension of wrist.

The result for coffee bean mixing is 13 which means that the worker is exposed to a very high risk that could lead to injuries. It is a must to implement change to reduce or eliminate risks in developing WMSDs. High task repetition and excessive exertion of force are some of the risk factors for the process. The risk factors for bagging coffee beans are repetition, trunk bending and over exertion of force while filling up the sacks, thus, resulting to a REBA score of 13. Change must be implemented to eliminate MSDs.

The total score obtained in the assessment of coffee bean weighing process is 14. Due to awkward postures such as heavy lifting, the workers are at risk while performing the task. For the last process, the total score is 13. It indicates a very high risk to have injuries. The awkward postures exhibited by the workers such as back extension, neck and trunk side bending, shoulder abduction, knee bending, and extension and flexion of wrist are possible contributory factors for low productivity among the workers.

Reference [41] shows that workers in chemical industries especially those who operate suspending agent workstations, face a risk of potentially developing musculoskeletal disorders (MSDs). The researchers performed an ergonomic assessment using REBA and obtained a score of 13 which indicates a very high risk and need to implement change.

Refence [20] shows that REBA was used to scale the workers' level of risk of developing musculoskeletal injuries. This study showed some specific movements that could risk biomechanical overload. Lumbar spine and shoulders were the areas of the body affected most frequently among workers. The method results in a final score that can range from 1 to 15 (non-existent risk -very high risk) and indicates the magnitude and priority of the measures to be taken.

Table IV
Summary of Upper Limb Assessment (RULA)

Process	Score	Awkward Postures	Remarks
Getting coffee beans from the storage	7	side bending of trunk and neck, back extension, abduction of upper arm, extension, and flexion of shoulder, and twisting of wrist	Investigate and change immediately
Pouring coffee beans on the floor	7	trunk bending, neck twisting, shoulder extension, and flexion and extension of wrist	Investigate and change immediately
Mixing Coffee Beans	7	side bending of trunk and neck, abduction, extension, and flexion of shoulder, upper	Investigate and change immediately

		arm abduction, and twisted wrist	
Bagging of coffee beans	7	neck and trunk bending, abduction, extension and flexion of shoulder, and extension and flexion of elbow and wrist	Investigate and change immediately
Weighing of coffee beans	7	twisting above waist, lateral bending, shoulder extension	Investigate and change immediately
Storing Mixed Coffee Beans	7	back extension, neck and trunk side bending, shoulder abduction, knee, and extension and flexion of wrist	Investigate and change immediately

Table IV displays the Summary of Rapid Upper Limb Assessment (RULA). The final RULA score for the first process is 7 which requires investigation to immediately change the way the process is performed. It is due to awkward postures demonstrated by the workers such as side bending of trunk and neck, back extension, abduction of upper arm, rising of shoulder (out of the neutral range position), and twisting of wrist. Pouring coffee beans obtained a score of 7 which indicates a very high risk to injuries and requires change to be implemented to reduce or eliminate the possible MSDs. The awkward postures demonstrated by the workers were trunk bending, neck twisting, shoulder extension, and flexion and extension of wrist.

The result for mixing coffee beans is 7 which means that the worker is exposed to a very high risk that could possibly lead to work related injuries. The results of the assessment require that change must be implemented to reduce or eliminate the possible MSDs. Excessive and sudden exertion of force and high task repetition are some of the risk factors for this process. The risk factors for bagging coffee beans are repetition of trunk bending and over exertion of force while filling up the sacks thus, resulting to a RULA score of 7. The result means that change must be implemented to eliminate MSDs.

The total score obtained by weighing coffee beans is 7. This is due to awkward postures from heavy lifting, where the workers are at risk while performing the task. For the last process, the total score is 13. It indicates a very high risk to potential work-related injuries. This is due to awkward postures displayed by the workers such as back extension, neck and trunk side bending, shoulder abduction, knee bending, and extension and flexion of wrist. The results show that workers are exposed in exhausting work activities which affects the level of productivity. The results show that each process experienced several awkward postures at the same time. If such work continues and could not be prevented, workers may suffer to MSDs.

RULA was used to analyze the preparation of plastering mortar, which is a generally used material for construction works. The posture of the employee was examined while preparing plaster mortar. The result of RULA analysis is calculated as 7 which indicates a high level of risk for the task and requires an ir[26]

	Total Back Exposure	Total Shoulder /Arm Exposure	Total Wrist/ Hand Exposure	Total Neck Exposure	Total Work Pace Exposure	Total Stress Exposure	Remarks
From the Storage	36	36	26	6	4	9	Moderate to high exposure level
Pouring Coffee Beans	36	36	34	6	4	9	High exposure level
Mixing Coffee Beans	28	24	34	12	4	9	Moderate to high exposure level
Bagging and Weighing	50	42	40	10	4	9	Moderate to very high exposure level
Storing	36	36	26	6	4	9	Moderate to high exposure level

Fig. I depict the summary of results using QEC for processes such as getting coffee beans from the storage up to storing the sack of beans to the storage area. For the first process, the worker has

a high level of exposure of risk at the back (36), shoulder/arm (36), and experience stress (9). The wrist/hand is at moderate exposure level as well as the work pace. The neck experienced a low level of exposure to risk.

For the second process, the back (32), shoulder/arm (36), wrist/hand (34), and stress (9) obtained the high level of exposure to risk. Meanwhile, work pace garnered a moderate exposure level. For the neck, it has low exposure level to risk. For the third process, the wrist/hand (34), neck (12), and stress (9) obtained the high level of exposure to risk. For the moderate exposure level to risk, the back, shoulder/arm, and work pace placed in this category.

For the fourth process, placing in a very high exposure level to risk are the back and the shoulder/arm. The wrist/hand and stress are within high level of exposure to risk. The neck and work pace are under the moderate level of exposure to risk. Lastly, the back, shoulder/arm, and stress have high risk exposure level.

Meanwhile, the wrist/hand and work pace experience moderate risk exposure level. Lastly, the neck is at low level exposure to risk. Most of the results are at high exposure level to risk which means change must be implemented as soon as possible.

Reference [2] used Quick Exposure Checklist (QEC) to assess the level of exposure of processors involved in Dewatered Cassava Mash (DCM) to work-related musculoskeletal disorder when using the locally developed traditional sieve in the sieving process. The observer and the processors assessment showed that the wrist/hand was the most stressed with the highest score of 40 followed by back and shoulder/arm with exposure score of 26 respectively and head/neck with exposure score of 16 given an Overall Exposure Level of 66% based on the Quick Exposure Checklist (QEC) rating.

Table V
WISHA Lifting Analysis Result

Process	RWL	LI	Remarks
Getting Coffee Beans from the Storage	85.5 lbs	1.67	High risk; may increase the risk of low back or lifting injury. Controls should be considered.
Weighing Coffee Beans	81 lbs	1.77	High risk; may increase the risk of low back or lifting injury. Controls should be considered.
Storing Mixed Coffee Beans	85.5 lbs	1.67	High risk; may increase the risk of low back or lifting injury. Controls should be considered.

Table V shows the WISHA Lifting Analysis results for the first process that covers getting coffee beans from the storage. The weight limit or lifting limit is 85.5 pounds. The value of limiting index is 1.67 which denotes that the task is high risk. The limiting index should be 1.0 or less than 1.0. As the limiting index increases, the level of injury risk increases as well.

For the weighing process, the calculation shows that the weight limit should be 81 pounds with a limiting index of 1.77. The actual weight is too heavy for the worker to lift. The worker doing the task is at risk and may suffer from injuries. In storing the mixed coffee beans, the lifting limit for this task is 85.5 pounds. The lifting index is 1.67 which is greater than 1 which means that the worker is exposed at work related risks while doing this task.

WISHA was used to assess manual lifting activity of industrial workers of Shiraz City. The variables including the weight of the object lifted, the position of the hands at the origin of lift or lowering, the frequency of lifting per minute in a shift, and the twisting angle while lifting were considered to analyze the lifting operation. In this method, the acceptable load weight is determined and then the load lifted is compared with the acceptable weight. If the weight of the load lifted by the workers is higher than the WISHA acceptable weight, then there will be a possibility for back injuries [4].

Table VI
Summary of NIOSH Lifting Equation (Lifitng Task)

Process		Origin	Destination	
Getting Coffee Beans from the Storage	RWL	38.72 lbs	33.31 lbs	Exceeded the capability of safely performing the lift. Must redesign.
	LI	3.7	4.3	
Weighing Coffee Beans	RWL	38.36 lbs	14.16 lbs	Exceeded the capability of safely performing the lift. Must redesign.
	LI	3.74	10.12	
Storing Mixed Coffee Beans	RWL	38.52 lbs	9.65 lbs	Exceeded the capability of safely performing the lift. Must redesign.
	LI	3.72	14.84	

The summary of NIOSH Lifting Equation result is shown in Table VI. For getting coffee beans from the storage, the recommended weight limit at the origin is 38.72 pounds and 33.31 pounds at the destination. The lifting index at the origin is 3.70 and 4.30 at the destination of lift. As shown in the result, the worker doing this task is highly at risk.

For weighing coffee beans, the vertical location of the hands is 37 inches at the origin and 8 at the destination. The horizontal location of the hands is 10 inches at the origin and 17 inches at the destination. The asymmetric angle is 0 at the origin and 90 degrees at the destination of the lift, and the frequency is less than 0.2 lift per minute for less than 1 hour. The coupling is classified as poor because the worker flexes the fingers about 90 degrees. The recommended weight limit at the origin is 38.36 pounds and 14.16 pounds at the destination. The lifting index at the origin is 3.74 and 10.12 at the destination of lift. The lifting index result is greater than 3 which means the lift is not safe.

For storing mixed coffee beans, the vertical location of the hands is 19 inches at the origin and 0 at the destination. The horizontal location of the hands is 8 inches at the origin and 24 inches at the destination. The asymmetric angle is 45 degrees at the origin and 45 degrees at the destination of the lift, and the frequency is less than 0.2 lift per minute for less than 1 hour. The coupling is classified as poor because the sack has no proper handle for the worker. The recommended weight limit for this task is 38.52 pounds at the origin and 9.65 pounds at the destination. The weight to be lifted (143.3 pounds) is greater than the recommended weight limit (38.52 pounds). Therefore, the lifting index is 3.72 which is greater than 3 and it means that the worker is at high risk and the task is physically stressful for the workers.

However, the recommended weight limit results are still unacceptable. According to Beckett and Co Solicitors, the maximum weight men should lift at work is 25kg. This relates to loads held close to the body at around waist height.

NIOSH was used to evaluate the brick stacking process. As a result of the analysis made at the origin and at the destination of the movement; The Lifting Index value (LI) for the origin was calculated as 3.55 and the LI value for the destination was 4.80. Since both values are greater than 3, the procedure is very risky and requires immediate ergonomic improvements. It was observed that the critical factor was the low frequency multiplier (FM) value which is related to the number of work repetitions per minute [36].

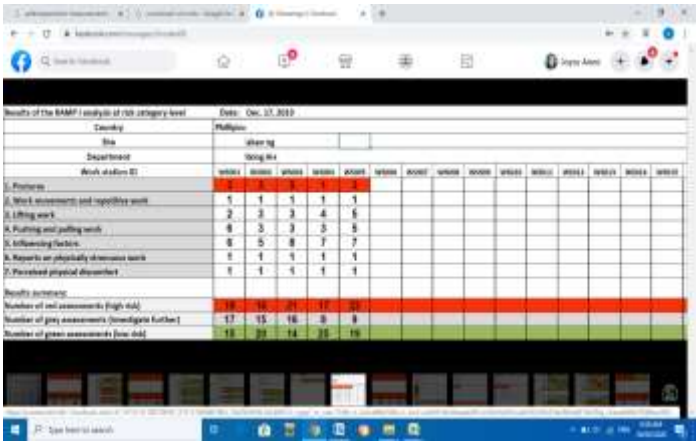


Fig. II
RAMP Results

Fig. II shows the results of RAMP analysis for each task. Each workstation ID represents the five tasks of the workers. Out of five tasks, three of them show the highest number in red assessments (high risk). The result of WS001 (getting stocks from the storage) is 19, WS002 (mixing process) is 21, WS005 (storage) is 22. The task situation with the highest result has such a magnitude and characteristic that many workers are at increased risk of developing musculoskeletal disorders. Improvement measures should be given high priority. These three tasks become the high-risk results because they exceeded the physical

capacity of the standard work. Postures and other influencing factors should undergo in a more in-depth analysis to assess the risk level. The risk of injury is affected by the load (such as exerted force, force direction, and posture) and time aspects (such as duration, recovery time, and frequency). Avoid transferring a risk from one worker to another and try to avoid introducing new risks when changes are introduced.

Table VII
CMDQ Result

	Frequency	Discomfort	Inter-ference	F*D*I	Percentage
Neck	22	16	12	4,224	7.91%
Shoulder (Right)	23.5	14	12	3,948	7.40%
Shoulder (Left)	23.5	14	12	3,948	7.40%
Upper Back	22	17	18	6,732	12.61%
Upper Arm (Right)	15	13	14	2,730	5.12%
Upper Arm (Left)	15	13	14	2,730	5.12%
Lower Back	20	16	17	5,440	10.19%
Forearm (Right)	13	11	16	2,288	4.29%
Forearm (Left)	13	11	16	2,288	4.29%
Wrist (Right)	24	17	14	5,712	10.70%
Wrist (Left)	24	17	14	5,712	10.70%
Hip/Buttocks	9	6	6	324	0.61%
Thigh (Right)	13	12	6	936	1.75%
Thigh (Left)	13	12	6	936	1.75%
Knee (Right)	11	15	10	1,650	3.09%
Knee (Left)	11	15	10	1,650	3.09%
Lower Leg (Right)	15	10	6	900	1.69%
Lower Leg (Left)	15	10	6	900	1.69%
Foot (Right)	4.5	6	6	162	0.30%
Foot (Left)	4.5	6	6	162	0.30%
				53,372	100.00%

As shown in Table VII, the total discomfort score for doing the manual mixing process (getting from storage, pouring, mixing, bagging and weighing, and storing) shows that 85.73% of respondents reported discomfort in the upper part of the body such as the neck (7.91%), shoulder (14.80%), upper back (12.61%), upper arm (10.24%), lower back (10.19%), forearm (8.58%), and wrists (21.40%). The respondents also felt discomfort in the lower part of the body such as hip/buttocks (0.61%), thigh (3.50%), knee (6.18%), lower leg (3.38%), and a little discomfort in the foot (0.60%).

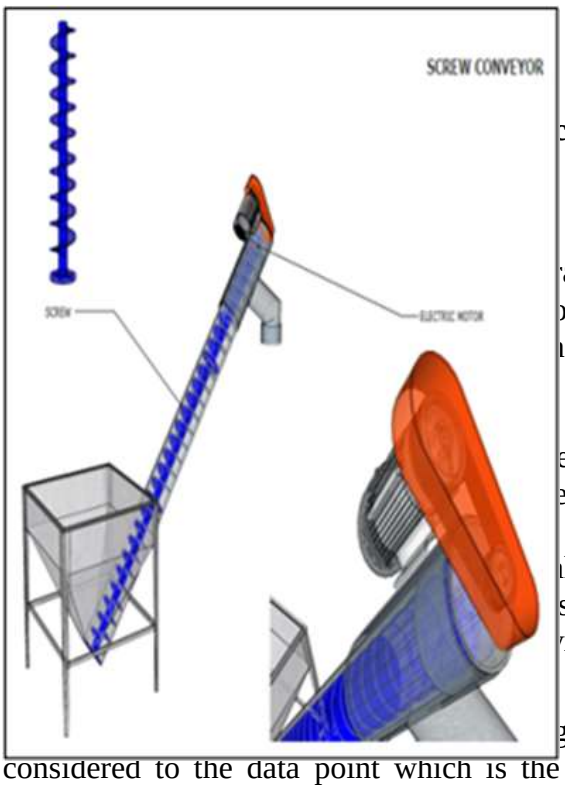
Results reveal that workers were experiencing discomfort most especially in the upper part of the body which means that they are more prone to risks and if not prevented, may result to more severe or serious injuries.

Based on the results of the assessment conducted, it can be interpreted that if the workers continue to work in the same posture, this can lead to development of MSDs in different parts of the body such as neck, trunk, and wrist. The workers were working at high risk levels and their neck,

trunk, and wrist were under physical strain. Most of the tasks were performed with trunk twisting and bending to unacceptable limit. It is recommended to take corrective actions as soon as possible.

Reference [10] shows, Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) was used to assess the discomfort of workers in a grocery store. The musculoskeletal discomfort score was calculated in accordance to the CMDQ scoring guidelines for the determination of the rate of discomfort and the quantification of the discomfort level. This study showed that in the upper and lower back, the feeling of discomfort felt subjectively by grocery workers was higher.

Design of Coffee Bean Mixer Based on Principles of Ergonomics



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ght are considered to the data point which is the elbow height standing. The 2-horsepower gear motor and the screw inside the tubular housing are the main components of the screw conveyor. The screw conveyor has a height of 9 feet from the ground. The inlet has a length of 2 feet and 3 inches and has a width of 2 feet and 3 inches. The brace used to support the inlet has a height of approximately 2 feet and 6 inches. The researcher used a diameter of 4 tubular housing as it is the most suitable size to convey the raw materials. The screw conveyor inclines 80 degrees which is considered a vertical screw conveyor. The gear motor used in the prototype meets and exceeds the height and inclination requirement of the prototype. The components and materials used in the conveyor passed the requirements to convey the materials.

Table VIII
Anthropometric Measurements

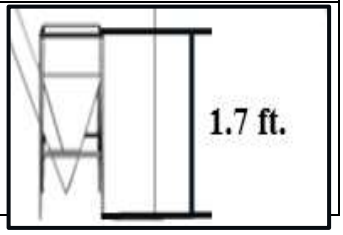
	Elbow Height Standing (cm)
Maximum Value	110.38
Mean Value	101.77
Minimum Value	93.16

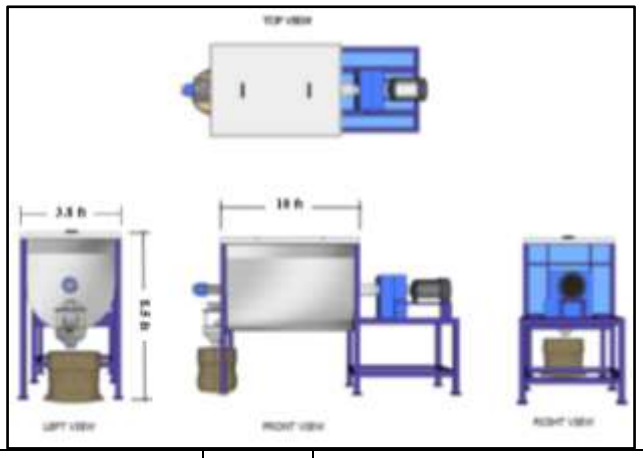
The table displays the maximum, average, and minimum value of elbow height standing worker. The anthropometric measurements of elbow height standing worker were obtained from 100 male samples. The maximum height value is 110.38 cm and the minimum height value 93.16 cm. The researcher considered the mean value as basis for the height of the weighing scale chute.

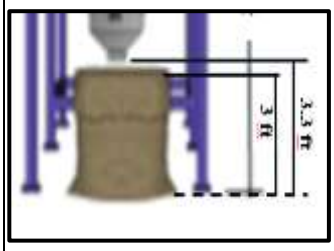
The design for the average is used with 101.77 cm instead of the design for the extreme taking the 95th percentile with 110.38 cm. The researcher evaluated that the 95th percentile value will be too high for the worker. Design for the average is often seen as a bad design because it only accommodates 50% of population, however, there are few cases where it is applicable. It is important for it not to be too high or too low and because the adjustability is not feasible.

Table VIII
Application of th ometric Measurements in tl f Machine

Gear Motor

Measurement Application to Machine Design	Mean Value	Figure
Screw Conveyor Inlet	101.77 cm / 3.3 ft	



Horizontal Mixer Weighing Scale Chute	101.77 cm / 3.3 ft	

The table displays the application of the Anthropometric measurements to the machine design. The mean value 3.3 feet of the screw conveyor is used as the basis of the inlet height. The worker will be using hydraulic cart when pouring the coffee beans to eliminate unnecessary lifting of the sacks which caused discomfort to them. On the other hand, the mean value of the mixer is used as the basis for the weighing scale chute height which is 3.3 feet. The measurement is associated to the dimension of the sack which is 3 feet in height.

Fig. IV
Mixer Machine, Top-Left-Front-Right View

Fig. IV shows the top, left, front and right view of the proposed coffee bean mixing machine. The proposed mixer is mainly made up of steel with electric motor, load cell, sensor, and ribbon type mixer blade. The mixer has a length of 10 feet; a width of 3.8 feet, and a height of 8.5 feet.

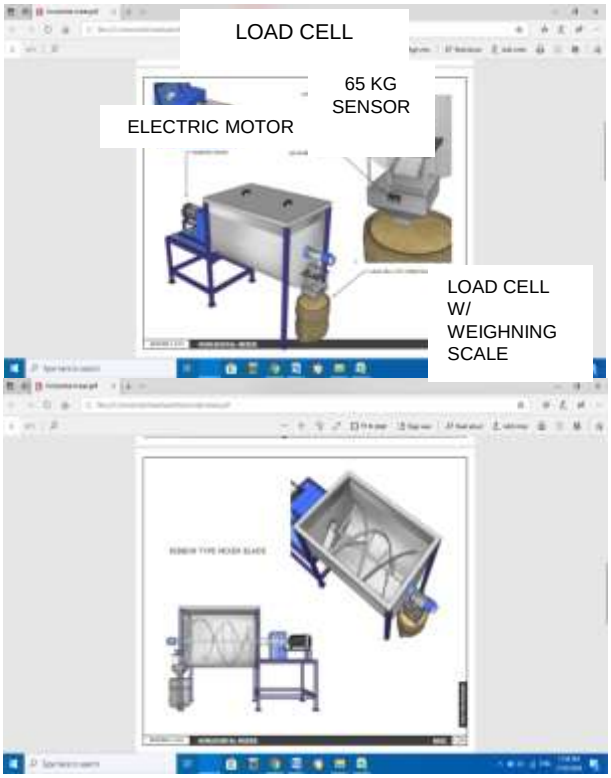


Fig. V
Isometric View-Electric Motor, Load Cell, Sensor, and Ribbon Type Mixer Blade

Fig. V shows the Isometric view of the mixing machine's electric motor, load cell, sensor, and ribbon type mixer. A 7.5 horsepower gear motor was used to run the mixer. The machine has load cell with weighing scale with 65 kg sensor. The machine will be using a ribbon type mixer blade having a U shape with a rotating agitator.

Table IX
Theoretical Impact of the Main Parts of the Proposed Machine

Main Parts of the Proposed Machine	Part Name	Function	Impact on Worker's Safety
	Inlet	Designed for bulk materials loading; it is used to store and fed coffee beans into the trough.	Worker's back and torso bending is lessened.

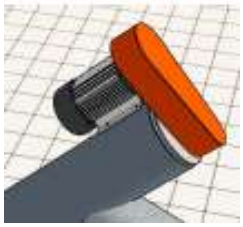
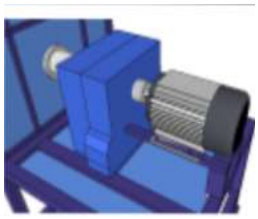
	Trough and Discharge Opening	The screw inside the trough rotates continuously and conveys the coffee beans through the transportation zone and discharges into the opening.	Eliminate the manual material handlin reducin the possibl work-related injury.			headed to the weighing scale.	
	Drive Unit	Enables the screw conveyor to transport the coffee beans using gravitational pull.	Avoidance of Carpal Tunnel Syndrome.		Weighing Scale	Provides accurate and reliable weighing of the discharge mixed coffee beans.	Removes the manual weighing method of workers. It eliminates long-standing duration and time-consuming weighing.
	Electric Motor	Generates the rotational force used to power a mixing machine.	Avoidance of Carpal Tunnel Syndrome.		Mixing Tank with Ribbon-type Mixer Blade	Mix different types of coffee beans with the use of a mixing blade to achieve the homogeneity of the output.	Gets rid of the repetitive manual mixing method and eliminate potential back injuries from twisting, turning, lifting and awkward postures.

Table IX (Continued).

	Discharge Chute	Allows the coffee beans to exit at the mixing machine and	Eliminates forceful shoveling of coffee beans going to the sack that may result to wrist tendonitis.

Table IX shows the parts of the proposed machine and the features that will aid to minimize or eliminate manual tasks operations. The table also depicts the how the proposed machine will help promote ease and efficiency among the workers particularly those who are assigned in the coffee bean mixing section.

Table X
Theoretical Impact of the Proposed Machine

Process of Mixing Coffee Beans	Impact to Body Parts	Focused Risk	Impact on the Worker/Process
Getting Coffee Beans from the Storage	Not reduced or eliminated	Forceful and excessive lifting of sacks	No impact, same as the existing process
Pouring Coffee Beans on the Floor	Bending of torso and excessive grip is minimized	Bending of torso and excessive grip for the wrist	Reduction of torso bending and excessive gripping on the sack
Mixing Coffee Beans	Manual process eliminated	Too much repetition of bending of torso, twisting of neck (upper body) and too much bending of legs (lower body)	No repetition of awkward postures and reduction of mixing time.
Bagging and Weighing Coffee Beans	Manual process eliminated	Too much bending of torso and legs, and excessive lifting of sacks	Forceful lifting is eliminated
Storing Mixed Coffee Beans	Not reduced or eliminated	Forceful and excessive lifting of sacks	Workers are not physically exhausted while storing because the 2 previous processes were eliminated.

Table X shows the impact of the proposed machine in terms of the eliminated risk factors and minimized exposure of body parts to potential work-related injuries. It is noticeable that not all risk factors identified in the process were resolved since the researcher only focused on the manual mixing process.

Fig. VI
Improved Process of Manual Handling Assessment Chart (MAC)

Fig. VI presents the improved process of manual handling chart assessment in getting coffee beans from the storage, bagging/weighing (lifting) of sacks, and storing mixed coffee beans. As shown in the figure, getting coffee beans from the storage could not be eliminated from the process. The color bands are just the same with the first result. However, to slightly reduce the risk factors avoiding sideways bending and torso twisting and any other awkward postures while lifting will help diminish the risk of injury. Lifting sacks to the weighing scale was eliminated and replaced by using a sensor that automatically fills up the sack with the required 65 kilograms of coffee beans. For storage, there was no other way to store the sacks but manually lift and push them with a cart. By using the mixer machine, the workers showed significant improvement. From the previous total

score of 53, now, the results improved with a total score of 36.

	From the Storage	Pouring Coffee Beans	To the Storage
Total Back Exposure	36	32	36
Total Shoulder/Arm Exposure	36	32	36
Total Wrist/Hand Exposure	26	24	26
Total Neck Exposure	6	6	6
Total Driving Exposure	0	0	0
Total Vibration Exposure	0	0	0
Total Work Pace Exposure	4	4	4
Total Stress Exposure	9	4	9

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pace, and stress exposure, respectively. The result of pouring coffee beans scored 32, 32, 6, 4, and 4 for the back, shoulder/arm, wrist/hand, neck, work pace, and stress exposure, respectively. The result of storing mixed coffee beans to the storage scored 36, 36, 26, 4, and 9 for the back, shoulder/arm, wrist/hand, neck, work pace, and stress exposure, respectively. The first and last task was just the same as the result of the first assessment while the task such as pouring coffee beans to the floor had low scores compared to the first assessment. These remaining three tasks could not be eliminated. However, exposure to risk factors was reduced because the tasks that give the workers high level of exposure to risks were eliminated.

Fig. VIII
Worker's Posture Using the Proposed Equipment

As shown in Fig. VIII, manual lifting, carrying and mixing of coffee beans will be totally eliminated with the use of the proposed intervention. It is also recommended for the worker to use a hydraulic cart in transporting and pouring coffee beans into the inlet of the screw conveyor to totally eliminate the risk factors associated with manual pouring of coffee beans. Worker will be using foot pedal to operate the hydraulic cart and a support from the other hand to lift the bin with a minimum force requirement. The worker will no longer need to perform manual weighing which was also considered as repetitive and strenuous work since weighing sensor was also integrated in the design of the machine. With this ergonomic intervention, work related musculoskeletal disorders will be eliminated while increasing the productivity in the coffee bean mixing process.

Table XI
Summary of Levels of Exposure to Risk Using Ergonomic Assessment Tools

Ergonomic Assessment Tools	Levels of Risk for Each Coffee Bean Mixing Process				
	Getting Coffee beans	Pouring of coffee beans	Mixing of coffee beans	Bagging & Weighing of coffee beans	Storing of coffee beans
Manual Handling Assessment Chart (MAC)	Medium to High Level of Risk	N/A	N/A	Low Level to High Level of Risk	Medium Level to High Level of Risk
Rapid Entire Body Assessment (REBA)	Very High Risk	Very High Risk	Very High Risk	Very High Risk	Very High Risk
Rapid Upper Limb Assessment (RULA)	Very High Risk	Very High Risk	Very High Risk	Very High Risk	Very High Risk

Quick Exposure Check (QEC)	Moderateto High Level of Risk	High Level of Risk	Moderate to High Level of Risk	Moderateto High Level of Risk	Moderate-to High Level of Risk
WISHA Lifting Analysis	High Level of Risk	N/A	N/A	High Level of Risk	High Level of Risk
NIOSH Lifting Equation	High Level of Risk	N/A	N/A	High Level of Risk	High Level of Risk
RAMP	High Level of Risk	High Level of Risk	High Level of Risk	High Level of Risk	High Level of Risk

As shown in Table XI, majority of the results of the risk assessment conducted using different ergonomic assessment tools imposed high level – very high level of risk. This clearly shows that workers are prone of developing musculoskeletal disorders that affects their capacity of performing their task.

Conclusion

The current process of manual mixing of coffee beans used un-ergonomically designed tools and equipment. While performing the tasks, the workers exhibited awkward postures. This includes twisting, bending and lifting that could potentially cause work-related injuries and affecting the workers' performance. To address the risk factors associated with the current process of mixing, engineering controls were provided through the proposed design of screw conveyor and coffee bean mixing machine.

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